WELDING JOURNAL

with TWECO CABLE Connections

There are warning signals in welding shops that are sometimes overlooked by busy executives. These signals mean lost arc time that almost invariably results in wasted man-hours, lowered production and less profit from the welding process. Heat belongs in the welding arc and no other place; when it appears elsewhere in the welding circuit, it is a signal that says, "Something is wrong." TWECO cable connections will improve your profit picture. Write for our "Causes and Cures" bulletin on this problem.

2 HUSKY MEMBERS of a sturdy welding family

TWECO stands guard over welding profits

A welding circuit is a pipeline for electric current; it can no more operate efficiently with poor connections than your garden hose at home. Poor connections are a menace to production and profits. If you "Weld with Tweco" you operate at maximum efficiency from the ground to the holder.

TWECOTONG is cool running in the toughest going. Avoid blistered operator hands and lost man-hours with TWECOTONG. There is a TWECOTONG for every job. Four models give a range to fit rod sizes and amperage needed. Unnecessary operator fatigue is avoided if you "Job-select" your holder from the TWECOTONG line. Remember too, that TWECOTONG'S tough multi-layer glass cloth "Super-Mel" tip insulation is quickly replaceable. Long lasting "Super-Mel" tip insulation (now standard on all models) is especially valuable where heats are extreme and service is severe. Switch to TWECOTONG for increased welding efficiency.

TWECOTONE PRICES

Model A-38	Model A-14	Model A-316	Model A-532
500 AMPS for 3/8–3/32" rod	300 AMPS for 1/4–1/16" rod	250 AMPS for 3/16–1/16" rod	200 AMPS for 5/32–1/16" rod
$6.50	$5.00	$4.75	$4.50

It is important to have a solid ground connection that is quickly removable and easily attached again to the work. INSIST on TWECO Ground Clamps for this purpose. TWECO Ground Clamps have powerful jaw grip for positive contact, easy-on, easy-off grounding. Junior and Senior clamps have a heavy copper braid between the jaws—welded-in so both will carry current. Insulated springs. High copper alloy construction. A size for every work requirement.

TWECO GROUND CLAMP PRICES

Model	Amp. Capacity	Cable Capacity	Price
Midget	125 Ampere	No. 6, 4, 2	$1.50
Jr.	300 Ampere	4, 2, 1, 1/0	3.00
Sr.	500 Ampere	1/0 thru 4/0	4.50

Write for Quantity prices. They save you 10 to 27%

Write for Twecolog #7 giving data and prices on the complete TWECO line of electrode holders, ground clamps and cable connections for electric welding.

Tweco PRODUCTS COMPANY

MANUFACTURERS OF ELECTRODE HOLDERS • GROUND CLAMPS • CABLE CONNECTIONS FOR ELECTRIC WELDING

ENGLISH AT IDA • WICHITA 1, KANSAS

YOUR TWECO DISTRIBUTOR CAN SUPPLY YOU

Today's biggest welder values!

HOBART "Pipeliner" 250 ampere gas dr. welder

LIGHT WEIGHT...EXTRA CAPACITY...EXTRA PEP...EXTRA LONG LIFE...YET COSTS LESS!

Faster, Smoother Welding The new "Pipeliner" was especially designed to speed up pipe line jobs. It has the typical Hobart characteristics of extra capacity and plenty of push behind the arc. Simplified controls provide for fine adjustment of wide welding range.

Lighter, but not skimped Rugged and compact, and economical to operate, this unusual unit is eager to meet every field condition. It can be loaded easily on a truck and hauled to the job.

Built to Stand the Gaff Pipe line construction calls for long hours of steady welding—grueling punishment for the average welder. But the new Hobart "Pipeliner" takes such hard usage in its stride. Delivers 1 KW Auxiliary DC Power for lights and small tools besides. No matter what your arc welder requirements may be, it will pay you to write.

HOBART BROTHERS COMPANY
BOX WJ-90, Troy, Ohio, U.S.A.

"One of the world's largest builders of arc welders"

The new HOBART A.C.

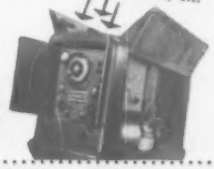
Efficient and quiet with no moving parts—not even a fan. Dual Control; Remote Control; "Pre-Surge" Inherent Arc Striking; Power Factor Correction; and many other features bring you new economy and speed in A.C. welding.

The HOBART D.C.

Ideal for production, maintenance, repair, and salvage welding in factories and shops. Made in 150, 200, 300, 400, and 600 ampere sizes, stationary or portable. Liberal ratings based on 60% duty cycle. Gives you more for your money.

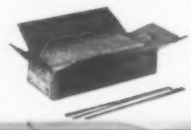
The Combination A.C.-A.C.

Actually two machines in one. Flip a switch and have either a full capacity A.C. Welder or a Power Plant for operating lights, tools, appliances, etc.



HOBART Simplified arc WELDERS

You'll like the Hobart No. 10 Rod If you are welding pipe lines, boilers, storage tanks, ships, or structural fabrications you'll find the Hobart No. 10 Electrode is just right. Sizes 1/8" through 1/4". Samples on request.



☐ Transformer Welder ☐ Pipe Line Special ☐ Electric Drive D.C. Welder ☐ Generator to "Build Your Own" ☐ Gas Drive 300 amp. ☐ D.C. Welder-D.C. Power ☐ A.C. Welder-A.C. Power ☐ Hobart Weldmobile

Free!

☐ Catalog showing complete line of Hobart A.C and D.C. Arc Welders

☐ Catalog on Hobart Electrodes

☐ Catalog on Hobart Accessories

Check and mail to:
HOBART BROTHERS COMPANY
BOX WJ-90, TROY, OHIO, U. S. A.

With no obligation, please send information on HOBART Arc Welders and other items checked.

Our work is: _____

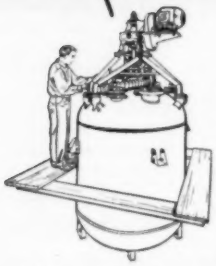
NAME _____ POSITION _____

FIRM _____

ADDRESS _____

MUREX

HELPS PFAUDLER MAINTAIN High Welding Standards



MUREX ELECTRODES

METAL & THERMIT CORPORATION
100 EAST 42nd STREET • NEW YORK 17, N. Y.

Newark
Philadelphia
Pittsburgh
Cleveland
E. Chicago, Ind.
Minneapolis
So. San Francisco

Murex Type FHP Electrodes play an important role in maintaining the high standards of welding set by The Pfaudler Co., manufacturers of glass lined and alloy processing equipment. This outstanding downhand electrode deposits weld metal of superior quality, and, at the same time is fast and easy to use.

Leading fabricators in many industries standardize on Murex — either to obtain better welding, or to achieve more economical production. Investigate Murex performance. Write for descriptive literature.

Mallory Designed Welding Dies

Add Speed, Uniformity, Economy To Production Welding

The Mallory designed and built die, pictured at top, welds an electrical contact to a reed in eight stations at a rate of 1000 units per hour. Each station is an independent unit that is easily replaced for dressing or repair. Each station has its own water cooling system and device for automatic ejection of welded parts.

No resistance welding production die is too large or too small for Mallory ingenuity.

Mallory designed dies are setting new standards of performance for uniform high quality at desired production rates . . . on single, double and multiple station equipment.

In addition, all Mallory designed dies afford the best possible operator motion efficiency . . . and feature easily removed inserts, low cost replacement parts, special alloys for maximum service life, and provisions for most effective water cooling . . . all combining for maximum economy.

That's service beyond expectations!

Mallory die design and building know-how is the result of more than 20 years of welding and alloy experience . . . enables Mallory to choose the best material for each job, the best design for the required results.

Mallory can supply complete Resistance Welding needs. Merely send prints, sample parts, production requirements, available machine data, platen dimensions. What Mallory has done for others can be done for you.

In Canada, made and sold by Johnson Matthey and Mallory, Limited 110 Industry Street, Toronto 15, Ontario

Resistance Welding Electrodes, Holders, Dies, Rod and Bars, Castings, Forgings

SERVING INDUSTRY WITH

Capacitors	Contacts
Controls	Resistors
Rectifiers	Vibrators
Special Switches	Power Supplies

Resistance Welding Materials

P. R. MALLORY & CO. Inc.

MALLORY

P. R. MALLORY & CO., Inc., INDIANAPOLIS 6, INDIANA

the

WELDING JOURNAL

published for the advancement of the science and art of welding by the

AMERICAN WELDING SOCIETY

Editor

W. SPRARAGEN

OFFICERS

O. B. J. Fraser	*President*
H. W. Pierce	*1st Vice-President*
C. H. Jennings	*2nd Vice-President*
R. S. Donald	*Treasurer*
J. G. Magrath	*Secretary*
F. J. Mooney	*Asst. Secretary*
S. A. Greenberg	*Technical Secretary*

DISTRICT VICE-PRESIDENTS

District #1—New York and New England
H. S. Swan

District #2—Mid-Eastern
Gerard E. Claussen

District #3—Southern
L. C. Stiles

District #5—Central
Fred L. Plummer

District #5—Mid-Western
J. A. Grodrian

District #6—Mid-Southern
Ray L. Townsend

District #7—Western
W. F. Boyle

volume 29 **SEPTEMBER, 1950** *number 9*

CONTENTS

technical papers, items and reports

Some Basic Problems in Design for Aircraft Welding, by J. Koziarski and K. B. Gillmore ... 709
Suggested New Welding Standards, by James F. Lincoln ... 715
Current Welding Literature ... 717
Flash Welding Nonferrous Materials, by F. L. Brandt ... 718
"Heliarc" Welding in Production, by T. E. Piper ... 723
Welded Aluminum Ammonium Nitrate Prilling Tower, by H. N. Hockensmith ... 729
Welding at the Railroad Reclamation Plant, by W. G. Muschler ... 733
What Is Needed in the Professional Training of a Welding Engineer, by John M. Parks ... 738
Development of Production Welding Techniques, by J. Raymond Wirt ... 740
Electric Utility Welding in the Shop and Field, by David P. O'Connor ... 745
Crack Sensitivity of Aircraft Steels, by A. W. Steinberger, B. J. DeSimone and J. Stoop ... 752

practical welder and designer ... 765 to 774

society and related events

Society News ... 776
News of the Industry ... 784
INDEX TO ADVERTISERS 785
Personnel ... 790
New Literature ... 796
New Products ... 804
Section Activities ... 816
Abstracts of Current Welding Patents ... 821
List of New Members ... 822
Annual Meeting Program ... 823

welding research supplement

The Influence of Biaxiality on Notch Brittleness, by D. Rosenthal and W. D. Mitchell ... 409-s
Interpretive Report Fabrication Division, Pressure Vessel Research Committee, by H. C. Boardman ... 422-s
Effects of Reduced Atmospheric Pressure on Arc-Welding Characteristics, by M. L. Begeman, B. H. Amstead and U. I. Mashruwala ... 433-s
The Projection Welding of 0.010 and 0.020-In. Steel Sheet, by E. F. Nippes, J. M. Gerken and J. G. Maciora ... 441-s
Transformation of Austenite in a Manganese-Molybdenum Steel Deposited as Weld Metal, by O. O. Miller, F. C. Kristufek and R. H. Aborn ... 450-s
Stress-Corrosion Cracking of Mild Steel, Discussion by R. N. Parkins ... 458-s
Effect of Low-Temperature Cooling Rate on the Ductility of Arc Welds in Mild Steel, by A. E. Flanigan, S. I. Bocarsky and G. B. McGuire ... 459-s
Comparative Tests of Different Types of Notch Impact Specimens ... 466-s
Mechanism of Fracture in the Tension-Impact Test, by W. H. Bruckner 467-s
Room Temperature Tensile Tests as an Index of Transition Temperature of Steel Plates, by Sadun S. Tör, Robert D. Stout and Bruce G. Johnston ... 477-s
Distribution of Locked-In Stresses in a Large Welded-Steel Box Girder, by John Vasta ... 484-s
Impact Tests of Welded Austenitic Stainless Steels, by V. N. Krivobok and R. D. Thomas, Jr. ... 493-s
Standardization of Welding in Germany ... 495-s
Elastic Theory of Pressure Vessel Heads ... 496-s

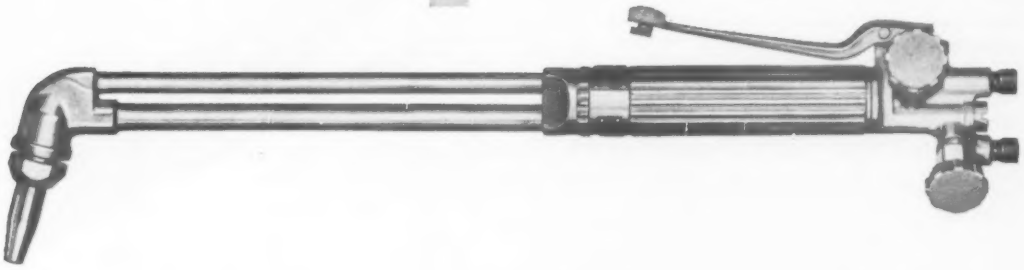
cover: Top cone for furnace without castings. Showing 3 of 4 uptake sections being fit to cone. *Courtesy Consolidated Western Steel Corporation.*

Published monthly by the American Welding Society. Publication office, 20th and Northampton Streets, Easton, Pa. Editorial and general offices, 33 West 39th St., New York 18, N. Y. Subscriptions $5.00 per year in United States and possessions; foreign countries $7.00. Single copies, nonmembers $.75; special issues September and October $1.00; members 75 cents. Entered as second-class matter January 5, 1932, at the Post Office at Easton, Pa., under the act of March 3, 1879.

Copyright 1950, by the American Welding Society. The Society is not responsible for any statement made or opinion expressed in its publications. Permission is given to reprint any article after its date of publication provided proper credit is given.

Do all this with *One* OXWELD Trade-Mark Blowpipe

- **Cut steel up to 12 in. thick**
- **Bevel parts for fabrication or repair**
- **Gouge grooves of many sizes and contours**
- **Deseam semi-finished steel forms**
- **Cut risers and "wash" pads**
- **Prepare plate edges for welding**
- **Remove rivets and pierce holes**
- **Trim plate and structural shapes**
- **Powder-cut stainless steels and other oxidation-resistant metals**
- **Cut guided circles and straight lines**
- **Scrap obsolete equipment for profit**



Whether your work includes one or more than one of these jobs, the OXWELD C-32 Blowpipe will save you time and money. This all-purpose cutting blowpipe, with its wide variety of inexpensive nozzles and attachments, easily handles these jobs—and many others—with outstanding efficiency, speed, and convenience.

Like all OXWELD products, the C-32 is built to give you many extra years of economical and **trouble-free service** under every condition of use. Available in your choice of 3 lengths (20-, 26-, and 32-in.) and 3 head angles (75-, 90-, and 180-deg.) to suit your exact needs. Write or phone today for full information about this cutting blowpipe — or regarding welding blowpipes, regulators, cutting machines, or acetylene generators.

The terms "Linde" and "Oxweld" are registered trade-marks of Union Carbide and Carbon Corporation or its Units.

Linde Trade-Mark

THE LINDE AIR PRODUCTS COMPANY
Unit of Union Carbide and Carbon Corporation
30 East 42nd Street UCC New York 17, N. Y.
Offices in Other Principal Cities
In Canada: DOMINION OXYGEN COMPANY, LIMITED, Toronto

New! VICTOR CUTTING TORCH

with Stainless Steel Head and Tube Assembly

CTS-400 Series

Rugged stainless steel tip nut, head and tubes.

Uses all standard Victor cutting tips.

New high-capacity, cutting oxygen valve—operated over half million times without detection of wear.

New oxygen and fuel control valves with "O" ring pressure seals—no outmoded packing, no take-ups, no adjustments needed.

Test it *on your severest cutting job . . . see for yourself how fast it cuts, how cool it stays.*

Here's the torch you've been waiting for. Cuts longer and faster than other torches without overheating because mixer and mixer tube are made of high-heat resistant copper alloys—no danger of mixer failures from overheating. Mixer itself is Victor's famous spiral mixer, designed to prevent backfire and flashback.

The stainless steel head and tube assembly is a single unit and can be replaced without buying a complete torch. Comes with either 90° or 75° head. Standard length is 21"; 27" or longer available on special order.

Call your Victor dealer NOW . . . ask him to demonstrate this new, stainless steel torch on your toughest cutting job.

VICTOR

Welding and Cutting Equipment Since 1910

Welding rods for all uses. Regulators for all gases up to 5000 psi. Machine and hand torches for welding, preheating, cutting, flame hardening and descaling. Portable flame cutting machines. Pneumatic filters and lubricators. Kinmont power positioners. Fluxes. Write today for free descriptive literature.

VICTOR EQUIPMENT COMPANY

3821 Santa Fe Ave.
LOS ANGELES 58

844 Folsom Street
SAN FRANCISCO 7

1312 W. Lake St.
CHICAGO 7

The WELDING JOURNAL

volume 29 September 1950 number 9

Some Basic Problems in Design for Aircraft Welding

Designers in aircraft must be practical, production-minded and know the limitations of materials. Metallurgical, corrosion, production, stress problems and a few specific applications are briefly covered

by J. Koziarski and K. B. Gillmore

INTRODUCTION

DESIGN, material and manufacturing are the three factors affecting successful production. They are of equal importance. Experience has shown that the neglect of any one of them or the inability to keep a proper balance has often been the source of very expensive failures. This is especially true of aircraft production.

The question of whether aircraft design is an art or a science and an aircraft designer an artist rather than a scientist has been often disputed. In our opinion he cannot be a true scientist because a scientist is always looking for bare facts. Facts whether derived from theoretical considerations or from experiment are the only factors which a scientist would consider. An aircraft designer, in spite of the tremendous development of modern science and technique, quite often lacks suitable data. In reality, if he were looking for facts only, he would never design anything. His fertile imagination, helped by his common sense, must always fill in the gaps in his established data.

One of the great thinkers said that a genius is made of 95% of hard work and of 5% of Lord's inspiration. This is equally true with an artist-designer. He is not born as a creator of aircraft. On the contrary, he must work hard to acquire the necessary background. First of all, he must be air minded and be at home with aerodynamics and mechanics of flight. These are his foundation. Secondly, an aircraft designer must know and understand well materials. This unfortunately is very often overlooked, although it is generally agreed that modern aircraft development depends in a great degree on material progress. The designers must also be familiar with stressing and in particular with dynamic stress problems. Almost nothing in an aircraft works statically. The designer is required to remember that what he puts on paper, is supposed to be easily and cheaply manufactured. There is no use designing an "excellent" machine if its production is impossible or too difficult. Consequently, aircraft designers must be production minded. Too difficult or too expensive operation may prohibit the use of an otherwise good aircraft. Ease of aircraft maintenance is very vital. These problems should also be familiar to him. It also is expected that an aircraft designer be well acquainted with drafting technique. Clearly, an aircraft designer cannot be an expert in all of these highly technical subjects. Nevertheless, he must know sufficient about their fundamentals to be able at least to evaluate recommendations made to him by the experts. The best aircraft designer is the man who can best maintain the engineering balance between the conflicting aircraft engineering requirements. The 5% of Lord's inspiration should balance enough other 95% of hard work to produce a good aircraft.

DETAILED CONSIDERATION

It would be impossible in a work of this size to deal with all everyday welding problems which face an aircraft designer. Consequently, we intend to limit our discussion to fusion welding and to show only a few of the simplest problems which have a fundamental importance. These problems are too often forgotten or underestimated. This is so because probably, they are too simple, and as such, apparently do not warrant any attention.

To some people welding looks so simple and so easy that they do not think it worthwhile studying its de-

J. Koziarski and **K. B. Gillmore** are with the Piasecki Helicopter Corp., Morton, Pa.

Scheduled for presentation at Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

tails. These people become careless; they either over or underestimate welding possibilities. One, should realize however, that although welding offers enormous advantages over other forms of joint, it also has its limitations.

Material Problems

One of the limitations in aircraft development is the lack of suitable materials. This lack hinders the efficiency of a modern aircraft and especially its power units. Unfortunately, a designer does not always know how to avoid material weaknesses and how to use its strength. This is especially true in welding. We intend to mention briefly only two sides of this problem: metallurgical notch and corrosion.

Metallurgical Notch. From the design standpoint an ideal joint would be that one which would offer complete internal structural continuity and uniformity. Although a weld or a welded joint most nearly approaches this ideal amongst known nonseparable joints it is structurally neither continuous nor uniform (Fig. 1).

Two things must always be born in mind when visualizing a weld: (1) that weld metal is a cast alloy while parent metal may be forged, rolled, etc. and (2) that, due to the secondary heat effect during welding, some physical-chemical changes occur in the heat-affected zone.

Consequently, these zones, having different structures, have also different properties. The structural discontinuity causes what is known as a "metallurgical notch." This discontinuity or notch may up to some extent be relieved by postwelding mechanical (e.g., peening) or heat treatments but cannot be completely eliminated. A metallurgical notch, although its effect may be tempered, will always exist in a weld.

If an evil cannot be avoided one should try to diminish its effect. Let us take a butt-welded tubular section (Fig. 2 (A)). It is not difficult to see that some working sections show 100% of heat-affected zone and the other 100% of healthy structure. The former are 100% under metallurgical-notch effect and, consequently, weakened and the latter exhibit parent material properties. This detrimental effect may be partly avoided by designing a scarf (Fig. 2 (B)) or fish-mouth weld (Fig. 2 (C)). It may easily be seen that in the case of the former the heat-affected portion of the working cross-section is more economically disposed than in the latter. Consequently, scarf joint is better than fish mouth and the latter should be designed only when there is no room for the former.

Corrosion Problems

Corrosion, this biggest enemy of metal, similarly to welding is often either over or underestimated. It is either feared or neglected by an average aircraft designer. It is feared because the majority of people see the destructive effect of corrosion without understanding its causes and, consequently, without knowing how to find the remedy. It lies in human nature to be afraid of the unknown and the mysterious. Today,

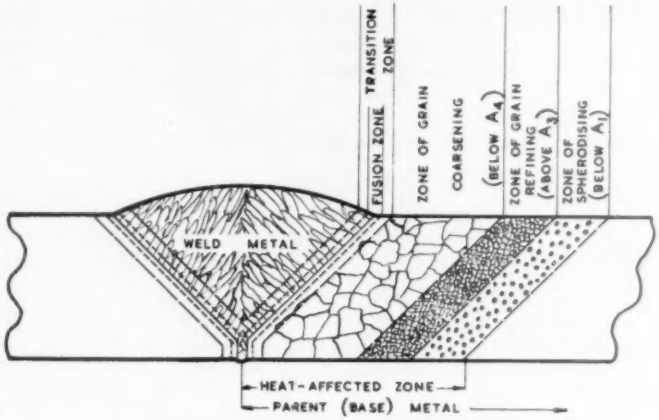


Fig. 1 Metallurgical Notch in a weld

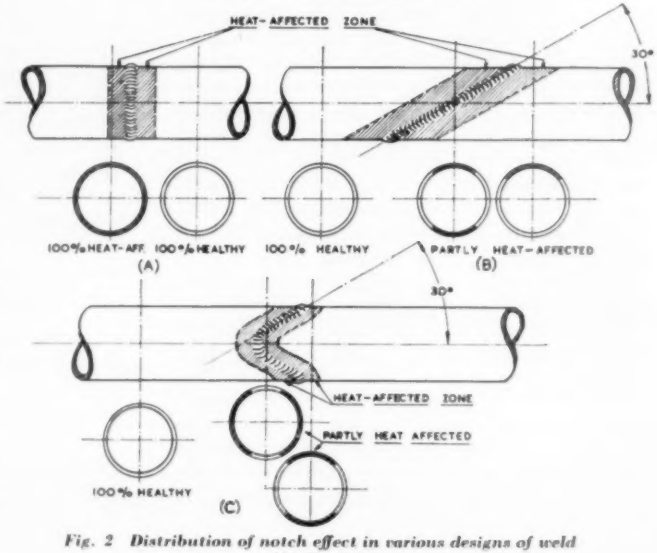


Fig. 2 Distribution of notch effect in various designs of weld
(A) Butt joint
(B) Scarf joint
(C) Fish mouth joint

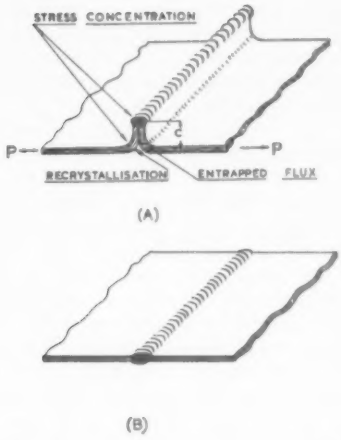


Fig. 3 Corrosion and stress concentration in a flange weld

(A) Incorrect
(B) Correct

however, there is no mystery about corrosion but its causes must be well known and understood in order to counteract its effect.

Let us see the simplest possible everyday joint; low gage aluminum-sheet flange welded (Fig. 3 (A)). If gas welding is used there is always tendency to flux entrapment in between flanged surfaces. If the gap is small enough, approaching capillary size, no post-welding cleaning may remove this flux residue which, being hygroscopic, sucks moisture and causes a fast corrosion. But even if no flux is used, like in shielded metal-arc welding, the gap may cause concentration cell corrosion. The best remedy against this is to make the flange only large enough to be completely melted during welding and the weld to have a shape of a butt weld (Fig. 3 (B)). This is typical of many other types of joint where there is a narrow gap welded up at one end. Yet, in most cases a little care in the detail design could eliminate this "corrosion trap."

Production Problems

A designer should always remember that things he designs should easily and economically be manufactured. There is no point in designing a "Chef-d'-Oeuvre" if it cannot be made or if it requires too extensive new installation of machines or equipment. It is remarkable how many difficulties are encountered in manufacture which could be avoided by quite minor changes in design.

Without looking for a too complex problem let us see a most common everyday welding-design error: a plate welded to a tube end (Fig. 4). A designer not familiar enough with welding processes will design an edge just large enough to accommodate the fillet weld. Such a weld, as is known, cannot be correctly executed. Due to unbalanced heat dissipation either there will be lack of fusion or the edge will be burned. Correct design

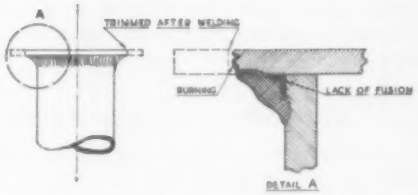


Fig. 4 Effect of an insufficient edge width

should provide a large flange which, when necessary, may be trimmed to desired size after the weld is done.

Stress Problems

No one will deny that a designer must be stress conscious; that he must avoid stress concentration. Unfortunately, welding, besides the previously described metallurgical notches, is a source of mechanical notches as well. These may take the form either of a slag inclusion, or of a blow hole, or of a lack of penetration or finally, of a sudden change of section of the weld toe (Fig. 5). The first three in the majority of cases are due to an unsuitable welding technique while the fourth one is an inevitable "malum necessarium" of a weld. Its detrimental effect may be nullified by machining the weld flash or partly diminished by a suitable design. Besides, blow holes or slag inclusions are not necessarily dangerous if not too large and if present not too close to the surface.

Let us go back to Fig. 2 (A). As easily may be seen in the case of such a joint, one working section would contain all around its circumference a stress raiser. Of course the effect of the mechanical notch would combine with the one caused by the metallurgical one. Consequently, fatigue strength of such a weld would be low. It may also be appreciated without any difficulty that the weld *C* and especially the weld *B* in Fig. 2 is superior to the weld *A*. Experience has shown that a weld inclined at 30° to the center line allows the best disposition of both mechanical and metallurgical notches along the working cross sections. Similarly to the previously discussed metallurgical notch, the scarf joint (Fig. 2 (B)) is superior to the fish-mouth one because a working section of the latter may contain four times as much of the heat-affected zone as the former. This again shows why a scarf weld should be designed wherever possible and a fish-mouth joint only where there is not enough space to specify a scarf joint.

The joint in Fig. 3 (A) shows another stress concentration in the case of a flange joint. There the weld metal and the bend of the flange are subject to addi-

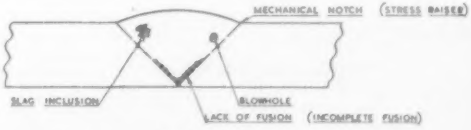


Fig. 5 Mechanical notches in a weld

tional stresses due to bending moment $M = Pe$. As discussed in the next section, weld metal as cast alloy does not like to be under flexure stresses.

STRESSES IN WELDED JOINTS

Considering how widely welding is used, it is remarkable how much confusion exists over the most efficient way to carry the stresses in a welded joint.

Welded metal being essentially a cast material, is most efficient if it can be used in compression. This is often impossible to achieve, and designers most commonly use a weld in shear, and it is widely held that a weld should never be used in tension. Yet, there is a large volume of evidence including no less an authority than the *Welding Handbook*, the official publication of the AMERICAN WELDING SOCIETY, that, in fact, weld metal is more efficient in tension than in shear. It is also very often easier to design away from stress concentrations in a tension joint than in a shear one. Tension, therefore, should come next after compression in the order of preferred stress, with shear taking only third place. Where a weld is used in shear, transverse shear is to be preferred to longitudinal shear. Bending and torsion should in general be avoided. Typical weld efficiencies, in percentages of the strength of the basic material are given by the *Welding Handbook* as

Compression	100%	
Tension	85%	For groove weld
Transverse shear	75%	For groove weld
Transverse shear	65%	For lap welds
Longitudinal shear	50%	For lap welds

These figures show another often neglected point—the greater strength obtainable from a groove as compared to a lap joint. This is shown in Fig. 6.

Figure 6 (A) shows how a groove weld keeps the weld material primarily in tension or compression, while the weld material in the lap joint of Fig. 6 (B) is subject to a combination of tension and shear. Moreover, the groove weld of Fig. 6 (A) has a minimum of stress concentration. It has of course the combined mechanical and metallurgical notches which are inherent in all welded joints, but the lap joint of Fig. 6 (B) has an additional stress concentration due to the sudden change in section at the start of the weld. It also puts into the joint a bending moment Pa due to the offset of the center lines of the two plates.

Even worse is the lap joint putting the weld in longitudinal shear as shown in Fig. 7. Yet, such joints are used in many places where one or other of the types of Fig. 6 could have been employed. There are, of course, certain design applications where a joint of this nature is required, and in such cases every effort should be made to make the details of the design such as to relieve mechanical stress concentration as far as possible.

Such joints are frequently designed as plain rectangular overlaps, and the length of the overlap made large to provide "plenty of shear area for the weld." In fact, the strength of the joint is almost independent of the length of the overlap, after a certain minimum is reached, all the load being carried by the two ends of the weld. This can readily be seen from some very elementary stress considerations. If the plates in Fig. 7 are subjected to an end load P, the stress in the material just outside the welded area is P/A, where A is the cross-sectional area of one plate. Just after the start of the weld, the two plates are forced by the weld to have the same strain, and therefore the same stress, at the joint line. The total load on the whole cross section must still integrate to P, therefore the load on each plate is $P/2$, or a load of $P/2$ must have been already transmitted across the first short length of weld. Until the other end of the joint is reached the load in each plate remains $P/2$, so no further load is transmitted across the weld and the center portion of the weld is almost unloaded as shown by the stress diagram (Fig. 7 (A)). Thus, theoretically there would be an infinite stress at each end of the weld, with zero stress in between.

In practice, this condition is relieved to some extent by local yielding of the weld metal permitting some redistribution of stress, as shown in Fig. 7 (A), but it still remains true that nearly all the load is carried by the welds at the end and the strength of the joint is almost independent of its length.

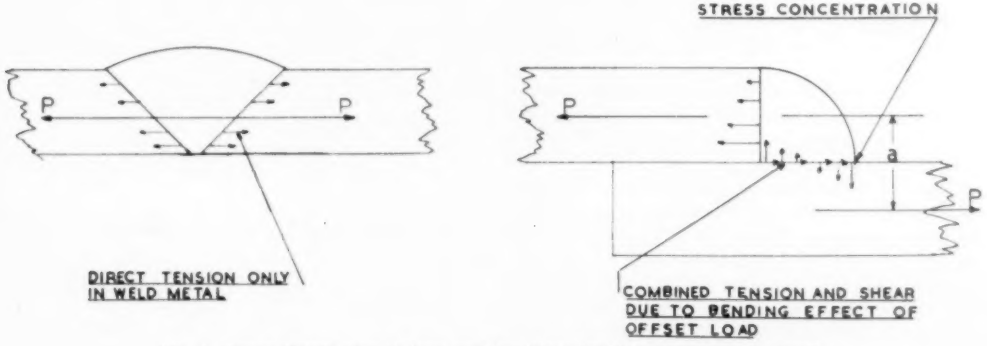


Fig. 6 Stress distribution in butt and lap joints (weld transverse to the load)

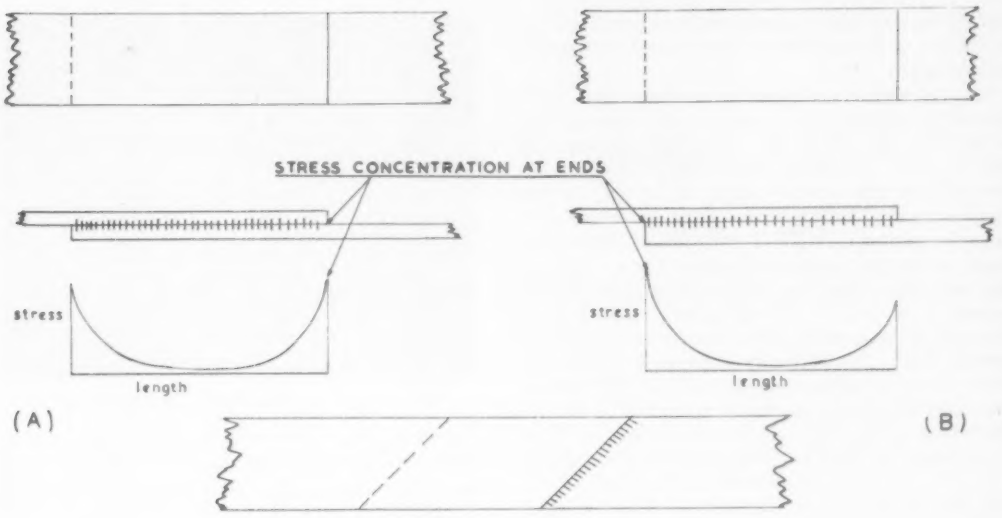


Fig. 7 Stress distribution in lap joint (weld parallel to the load)

Moreover, this high concentration of stress at the end of the weld is occurring at a point which is already relatively weak due to inherent welding difficulties.

If the plates are of unequal thickness or unequal elastic properties the distribution is changed only in so far as the two end peaks become unequal, in the ratio of the thickness of the two plates as shown in Fig. 7 (B). This case is often found where a small fitting is joined to a large member.

If, however, the joint is scarfed as in Fig. 7 (C) then the load can be distributed from end to end of the scarf, with a comparatively large reduction in stress concentration.

APPLICATION TO TUBE-END FITTINGS

The above principles can be readily applied to more complex forms of joint. As a next step, the case of a lug end welded into a tube may be considered.

This is frequently designed as shown in Fig. 8 (A), yet this design incorporates a number of weaknesses which can be readily eliminated by a little more attention to detail.

The square-cut end to the plate gives precisely the type of stress concentration just discussed for a lug weld—the sudden change in cross section not only is a stress raiser in itself, but also forces a concentration of loads in the extreme end of the weld. By relieving the inside of the plate and cutting it at an angle as shown in Fig. 8 (B), this can be avoided.

Again, the narrow edge of the plate protruding from the tube will result in poor weld penetration, so that there is not only a high stress concentration, but it occurs at an already weak spot in the weld. By finishing the plate flush with the tube as shown in Fig. 8 (B), the full strength of the weld can be developed at the critical edge, and the plate can be swelled out later, if required in a region where the weld is carrying little or no load. In such a manner the area of unfavorable welding condition accompanied by bad penetration is

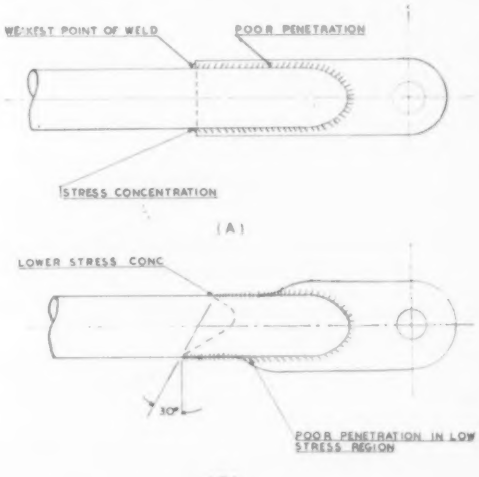


Fig. 8 Design of tube end fitting

(A) Incorrect
(B) Correct

shifted from the point of maximum stress concentration at the end of the plate toward the area with low stress concentration.

Exactly similar conditions occur in a cluster joint between a number of tubes running to a common point. A typical fatigue failure in such a joint is shown in Fig. 9. Here the stress concentration at the joint between the tube and the gusset is due only to the straight edges of the gusset, as there is ample edge distance for welding. On the opposite side (*A*) where two tubes are welded together directly without a gusset, the weld metal is forming a bridge and as it shrinks on cooling, it tends to distort both tubes by pulling them together and so involves initial stress in both the tubes and the weld. In addition the acute angle between the tubes causes a tendency to over heating. The end of this weld is exactly opposite the end of the gusset so that both stress concentrations occur in the same cross section of the tube. Examination of the actual parts in this case indicated that the failure had started at point *A*. By relieving the gusset between the tubes and arranging its end 30° across the tube from *A* the stress concentration could have been greatly reduced and the failure most probably avoided.

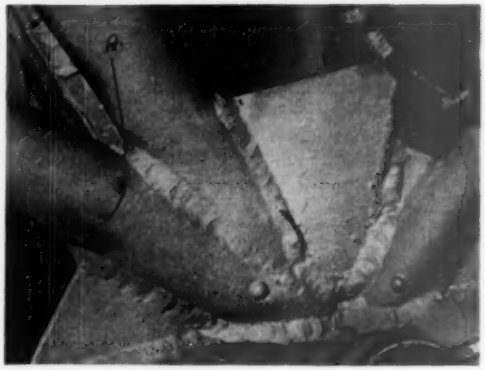


Fig. 9 Typical fatigue failure of a cluster joint

CONCLUSION

It has not been possible in this paper to touch on more than a few of the problems of aircraft welding. It has been our object, however, rather to put these problems in their correct perspective, and show how careful attention to the application in a detailed design of a few very well known, but often neglected, fundamental principles can make the difference between a satisfactory and an unsatisfactory product.

A designer should remember that a fusion-welded joint has some degree of continuity and uniformity and a welded structure can therefore be considered as an approach to a solid piece with some inherent stress concentrations at the joints. He should consider his stress concentration due to changes of section on this basis and he should not attempt to translate directly from a riveted joint in which the attachment is made at a few local spots only. He also should remember that he cannot be his own welding expert and he should therefore seek the advice of those with experience of welding processing at all stages of the design, even on an apparently simple joint to insure that his design can be satisfactorily manufactured.

ACKNOWLEDGMENT

We would like to express our thanks to the management of the Piasecki Helicopter Corp. and to L. L. Douglas, Chief Engineer for making available to us the company's facilities and technical data for use in the preparation of this paper.

DO YOU WEAR YOUR A.W.S. EMBLEM?

Our Emblem signifies that you are contributing to the advancement and perfection of welding and welding engineering through active participation in the American Welding Society.

For those who have not received their blue and gold A.W.S. Emblem, we carry a supply at National Headquarters, 33 West 39th St., N.Y.C.

In 10 Kt. Gold @ $2.75 for 3/8" and $4.00 for 1/2" sizes
In Gold-Plate @ $1.20 for 3/8" and $1.35 for 1/2" sizes
(Available with Safety Catch or Screw Back. State preference)

(Money Order or Check)

WEAR your A.W.S. Emblem

Suggested New Welding Standards

A plea for simplification of welding standards and elimination of unessential testing

by James F. Lincoln

IN APPROACHING the subject of possible changes in arc-welding electrode standards, it would seem to me there are two facts that should be primarily considered.

The first is that there have been many billions of welds made in all kinds of structures which have been in operation for many years, successfully. Arc welding is a fully proved process.

Secondly, if standards are to be of maximum benefit, it is necessary to have tests which can be easily made on the job to the entire satisfaction of the people who are interested and responsible. What is offered here is thought to be just that. While it is different, these suggestions are given without thought of criticism of what has gone before.

When we consider the fact that the deposited metal from all mild-steel electrodes is practically identical, except for the intermingling of the plate metal with the deposited metal, it is obvious that a great many of the specifications which attempt to distinguish between the various types are not necessary. These specifications have the added disadvantage that the uninitiated, in reading these complications, is lead to believe that welding is an extremely difficult process, and that great care and education are necessary to distinguish between unimportant differences.

There are also many specifications regarding the flux characteristics of the coating. This should be a subject dealt with between the manufacturer and the user. Such details have nothing to do with the quality of the weld, but have to do only with the ease of operation in the various applications.

We would not think of specifying the number of brushes that would be used, the speed of rotation, the type of insulation and the mechanical dimensions of a welding machine. These details are of interest to the customer and are always a matter of agreement between the buyer and the seller. Certainly they have nothing to do with technical specifications.

James F. Lincoln is President, The Lincoln Electric Co., Cleveland, Ohio.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., Oct. 22-27, 1950.

In the same way, the type of coating, what it is made of, how the slag can be removed, whether it can be used on alternating current or direct current, whether it is straight polarity or reverse polarity, are all matters of satisfactoriness of operation in the individual cases and also of preference by the user.

It is obvious that any weld could be successfully made with any standard electrode in mild steel. The only difference is the relative skill needed and the ease and speed of operation, none of which has anything to do with a technical specification. Therefore, all such restrictions and information should be eliminated from specifications and should be a matter of application by the manufacturer producing the shielded-arc electrodes.

It would seem to me the restrictive nature of present standards is perhaps normal during the development of a process which is as important as arc welding. There is no doubt, however, now that we have long experience, that a new view should be now taken of this matter. The following facts will show why I believe this.

The previous method to welding of joining plates has been by the use of the riveted joint. This has been the method used for generations and with fairly satisfactory results. However, welding has many advantages over riveting—lower cost, greater strength and greater ease of operation. These advantages have often been handicapped by our present standards which have greatly increased costs and complications far beyond what is necessary, as long experience has shown.

The approach under present standards develops a number of strange results. For instance, if there are two joints in mild steel plate, one made by welding and one by riveting, and they are of equal strength in tension, the riveted joint would be accepted and the welded joint rejected under present standards.

If the same two joints were tested for ductility and were equal, the riveted joint would be accepted and the welded joint rejected under present standards.

If the same two joints were examined for voids, such as porosity, the riveted joint would be accepted and the welded joint rejected under present standards.

If the same two joints were inspected for tightness against pressure, which in the case of riveted joints is done by upsetting the edge with a chisel, this undercut would be accepted in the riveted joint, but the welded

joint, with the same undercut, would be rejected.

If these two same joints were examined for appearance and were identical as to looks, the riveted joint would be accepted, the welded joint rejected.

If these joints were to be tested, however, to anywhere near the ultimate strength of the metal, the riveted joint would be destroyed and any welded joint of full section would be perfect.

If a structure is to be made and it is to resist high pressures, as are shown in the Boiler Code, stress relief is necessary under the rules for welding, thus greatly reducing the strength of the structure. Riveting, with all of the above handicaps, would be accepted without stress relief.

Because of this skepticism written into present welding standards, whenever there is a failure of a welded structure, it is always the welding which is criticized, never the design, which is usually the reason.

This is not true in riveting. No riveted job is suspect. Failure is thought of as an accident, only. As an example, there were a number of ships which broke in two, some while standing at a dock, others in actual operation. Without hesitation the welding was cited as the reason, although the welds themselves in almost all cases showed no defects and the welded joints themselves did not break. The break was from the tearing apart of the plate. The broken riveted ships were accepted as normal, no notice being taken of them. We have been subjected since that time to thousands of pages of explanations, most of which are critical of welding; none of which criticized the design which was the actual cause of the failure.

We see castings when improperly designed which break in cooling after pouring. We do not criticize the casting method and write rules against it. We strengthen the weak section and cuss the designer for his oversight.

The problems of the broken ships are design failures, even when we try to make welding the scape goat.

If we are to have new welding electrode standards, what would be the correct approach? It would seem to me we ought to recognize a number of things; first, that the metal we are dealing with is very carefully selected steel of very restricted chemistry. The physical characteristics of this steel are completely known to all versed in the art when this chemistry is known.

Second, we are depositing this metal in an electric arc which has always been thought of as a preferable way of melting metal, compared to the gas flame as is used in open hearth, usually used in making steel. The steel in the plate made in the open hearth is generally accepted without question. The weld metal, which is very carefully selected and deposited under the arc with complete protection from contamination of the air, is specificationed to death.

Why not think of welding as the joining of two plates together with material which is equally good or better than the material in the plates themselves. That is what it is. If we do that, then our problem largely disappears. We think then of two plates being made into one homogeneous whole, and properly so. We can be completely sure in the case of mild steel that in the ordinary welding where a full section of weld metal is added to the plate, that the strength of this joint will be greater than the strength of the hot-rolled plates themselves. This is because of the annealing action of the plate because of the high temperature at the time of rolling.

It is difficult to understand what more the weld can do than to join the two plates together with a weld so they are equally strong or stronger than the plates themselves. Greater strength is of no benefit to any one.

Perhaps there would be some question as to whether the weld itself had been properly made, whether there were voids in it. Much attention is given to this in the specification. These voids are not found in the structure by testing a testpiece. It does not follow that because a man makes a good joint in one place that of necessity he will make nothing but good joints. However, if we are going to use the welded structure there is no reason why tests short of destruction could not be made of that structure that assures safety. This is the same test which is used on most structures of other kinds, and since they have been successful there, they would be in the case of a weld.

There is one more criticism of the present standards which is obvious. In general, all tests are made by bending a test sample made by the operator with what is called face bend, side bend and root bend tests. Theoretically, perhaps, it would be possible to have a test of this kind be indicative of something. Practically, it is doubtful if it can be a practical test, the reason being that it is obvious that in all of these tests we are stretching a plate plus a welded joint. Obviously, if the plate is stronger than the weld, the plate will force the weld to do all of the stretching, in which case the weld will break because it will be stretched way beyond its ability to elongate.

If, however, the weld metal is stronger than the plate, the plate does all of the stretching and often breaks, and the weld stretches not at all. This is no test of the weld. Actually, what happens is usually between these two. The weld in cases where the plate is stronger than the weld metal can be perfect in every detail, yet will fail in every test. If the plate is a purer, softer material, lower in carbon and manganese, the bend would take place entirely in the plate and the weld metal would not stretch.

Obviously, a test of this kind is useless as a distinguisher of quality. The best indication of this fact is that in the higher strength steels, which are now being used in pipe lines and in other strong steel applications, these tests are made, but since the weld metal or the plate in the heat-affected zone always fails, they merely throw the tests aside and proceed with the welding

without these tests. The results, however, have been universally successful.

With all this in mind, would it not be well to approach this problem in a new way. If testing is what we want, then let's make certain first of all that the weld metal is as strong or stronger than the parent metal. This can be done by stretching a testpiece to destruction and see that the break takes place in the parent metal.

The only other test is to make sure the weld metal and the plate are properly paired. For instance, we may be using high carbon steel in the electrode when low carbon steel should be used. This can be found out by making a weld and actually measuring the elongation of the weld metal by a transverse bend and setting up standards for it. Obviously, if the weld is as strong or stronger than the plate, and if the bend test as described above shows weld metal like the plate, other tests are of no possible value. Both of these tests can be made very easily, very quickly and very cheaply.

Any inspector who has any welding experience can tell by appearance of the finished weld whether proper technique has been used. In fact, an operator could not weld otherwise without its being completely apparent.

When the welding is to be done on the other 5% of metal, that are alloys, the same relative standards could be used, the same method of test could be followed with proper comparable standards and characteristics.

Here is a usable plan to properly control a very rapidly growing industry. Do not handicap it. It is not well to try to apply the same rules to a man at maturity that we did when he was a child. Welding has come of age. Let's treat it so.

CURRENT WELDING LITERATURE

Airplane Carriers. H. M. Aircraft Carrier "Ark Royal." Engineering, vol. 169, no. 4398 (May 12, 1950), p. 543; see also Engineer, vol. 189, no. 4920 (May 12, 1950), p. 579.

Airplane Landing Gear. Pressure Welds with Parent-Metal Strength, L. Van Camp and C. E. Levoe. Welding Engr., vol. 35, no. 5 (May 1950), pp. 26–28.

Bridges, Steel, Australia. Australia's Welded Highway Bridges, V. Karmalsky. Eng. News-Rec., vol. 144, no. 22 (June 1, 1950), pp. 39–41.

Dredges, Diesel. Suction Dredger for Pumping Gravel. Engineering, vol. 169, no. 4400 (May 26, 1950), pp. 595–596, (illus.) 598; see also Engineer, vol. 189, no. 4923 (June 2, 1950), pp. 652–653.

Electric Welding, Arc. Control of Distortion in Arc Welding, R. G. Braithwaite. Inst. Welding—Trans., vol. 13, no. 2 (Apr. 1950), pp. 64–70, 2 supp. plates.

Electric Welding Machines, Control. Engineering Trends in Spot Welder Controls, S. C. Rockafellow. Electronics, vol. 23, no. 7 (July 1950), pp. 70–73.

Electric Welding Machines, Resistance. Spot Welder for Light Gauge Work. Engineer, vol. 189, no. 4918 (Apr. 28, 1950), p. 512.

Electric Welding. Power Supply for Multi-Transformer Welding Presses, T. F. Ellis. Power, vol. 94, no. 6 (June 1950), pp. 94–96, 220.

Furniture Manufacture. Production Brazing, C. E. Swift. Welding Engr., vol. 35, no. 4 (Apr. 1950), pp. 36–38.

Gases, Inert. Economical Inert Gases Serve Industry in Many Ways, E. J. Junk, Jr., and C. M. Kemp. Indus. Heating, vol. 17, no. 1 (Jan. 1950), pp. 58–60, 62, 64, 66, 68, 70; no. 2 (Feb.), pp. 242, 244, 246, 248,260.

Hardness Testing Apparatus. Six Advantages of Scratch Hardness Testing, J. H. Hruska. Welding Engr., vol. 35, no. 4 (Apr. 1950), pp. 17–19, 22.

Heating Sidewalks. No Snow Next Winter! J. M. Heller. Welding Engr., vol. 35, no. 5 (May 1950), p. 25.

Instruments, Manufacture. Precision Instruments. Precision Welded, L. H. Judge. Welding Engr., vol. 35, no. 4 (Apr. 1950), p. 39.

Materials Handling. Special Equipment Handles Heavy Components, A. I. Nussbaum. Am. Mach., vol. 94, no. 9 (May 1, 1950), pp. 76–77.

Metals Testing. Account of Henri M. Schnadt's Ideas on Strength of Materials, and His Testing Methods, R. Weck. Inst. Welding—Trans., vol. 13 no. 2 (Apr. 1950), pp. 41–56.

Pipe Fittings. Strict Production Controls Assure Precision-Manufacture of Welding Pipe Fittings, P. R. Becker. Steel, vol. 126, no. 24 (June 12, 1950), pp. 95–98, 100.

Pipe Lines. Quality Pipe Welding . . . How It's Achieved, E. P. Everhard. Heating, Piping & Air Conditioning, vol. 22, no. 3 (Mar. 1950), pp. 93–94.

Pipe, Steel. "Double Ending" Saves Welding Time, Cuts Handling. Welding Engr., vol 35, no. 4 (Apr. 1950), pp. 24–25.

Pipe, Steel, Manufacture. From Steel Plate to 16 Inch Pipe, W. A. Connor. Can. Metals, vol. 13, no. 3 (Apr. 1950), pp. 28–30.

Pressure Vessels. Manufacture of Fusion Welded Pressure Vessels. Engineer, vol. 189, no. 4914 (Mar. 31, 1950), pp. 385–388.

Pumps, Manufacture. World's Largest Pumps for Grand Coulee Dam, W. E. Christison. Welding Engr., vol. 35, no. 5 (May 1950), pp. 22–24.

Ship Salvaging. Underwater Welding Aids Ship Salvage, R. H. Burks. Welding Engr., vol. 35, no. 4 (Apr. 1950), pp. 20–22.

Silver Soldering on Intake Manifold Line, W. J. Hutts and W. F. Rader. Western Machy. & Steel World, vol. 41, no. 2 (Feb. 1950), pp. 63–65.

Solders and Soldering, R. W. Mebs and W. F. Roeser. U. S. Bur. Standards—Cir. 494 (April 28, 1950), 12 pp., 15¢.

Stainless Steel. Low-Carbon Stainless Steels Make Possible Savings in Welded Fabrication, J. B. Campbell. Matls. & Methods, vol. 31, no. 4 (April 1950), pp. 63–66.

Steel Castings. Redesign Steel Castings. Steel, vol. 126, no. 23 (June 5, 1950), pp. 92–94.

Steel. Weldability of Plain Carbon and Low Alloy Steels, E. B. Suters. Australasian Engr., vol. 43 (Apr. 1950), pp. 35–44.

Towers, Welded Steel. Encasing Structure for Hot Water Accumulator for Pimlico District Heating Scheme, G. Wilson. Structural Engr., vol. 28, no. 4 (April 1950), pp. 85–90.

Welded Steel Structures. Design in Welded Structures, J. S. Terrington and M. D. Brisby. Civ. Eng. (Lond.), vol. 45, no. 524 (Feb. 1950), pp. 96–98; no. 525 (Mar.,) pp. 164–166; no. 526 (Apr.), pp. 244–246.

Welded Steel Structures. Research on Welded Structural Steelwork. J. W. Roderick. Inst. Welding—Trans., vol. 13, no. 2 (Apr. 1950), pp. 57–63.

Welded Steel Structures, Stresses. Maximum Beam Moments in Welded Building Frames, M. R. Horne, Structural Engr., vol. 28, no. 5 (May 1950), pp. 109–115.

Welded Structures, S. M. Reisser. Can. Machy., vol. 61, no. 4 (April 1950), pp. 208, 210, 212, 214, 216; no. 5 (May) pp. 152, 154, 156, 158–161.

Welders Training. Welding Goes to College, R. C. Wiley. Industry & Welding, vol. 23, no. 3 (March 1950), pp. 26–28, 62–65.

Welding. Trends in Fabrication by Welding, S. V. Williams. Can. Metals, vol. 13, no. 1 (Jan. 1950), pp. 39–43.

Welding Shops. Large Welding Shop Extension. Engineer, vol. 189, no. 4918 (Apr. 28, 1950), pp. 515–516.

Welding. Survey of Modern Theory on Welding and Weldability, D. Seferian. Sheet Metal Industries, vol. 27, no. 275 (Mar. 1950), pp. 241–253; no. 276 (Apr.), pp. 339–346; no. 277 (May), pp. 435–444.

(*Continued on page 728*)

Flash Welding Nonferrous Materials

Comparison of the equipment and procedures for flash welding nonferrous materials with ferrous materials. New developed techniques are described and welding conditions and results are tabulated

by F. L. Brandt

THE flash welding of ferrous materials is relatively simple just as the spot welding of ferrous materials is relatively simple. The wide plastic range of the ferrous materials combined with the ability to retain the heat permits satisfactory joint strength over a wide range of combinations of the variables. The highest quality machines, controls and supervision are required to produce consistent high-strength spot welds in nonferrous materials such as aluminum. Production control demands strict upkeep of equipment and methods. The widespread spot and seam welding of aluminum alloys in aircraft manufacture has developed the art. The application of flash welding to aluminum and other nonferrous materials is now in rapid development; and just as in the case of spot and seam welding, equipment with precise control of the variables is required.

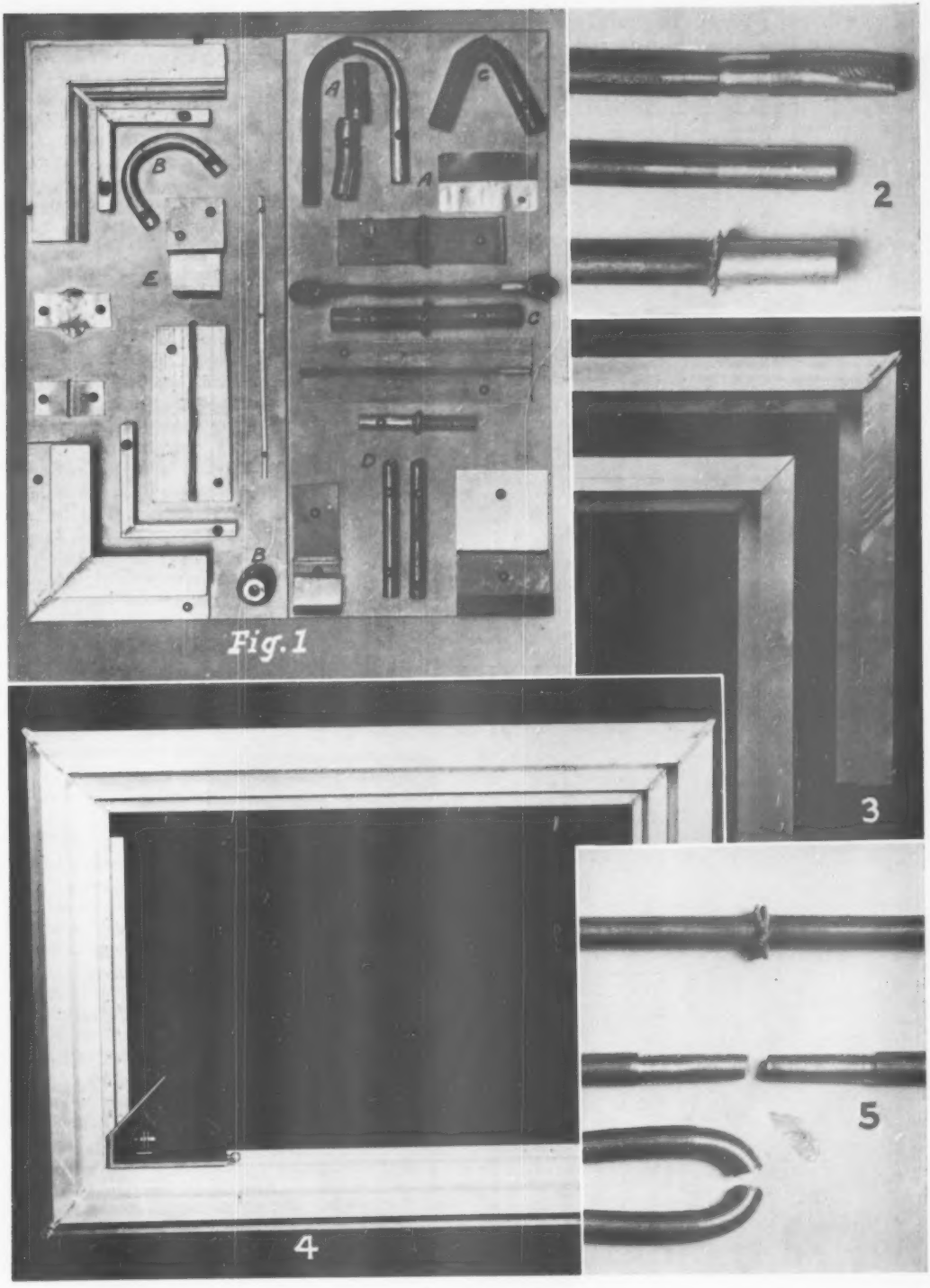
All flash welding requires excellent alignment of the finished product. Not only is alignment required in the interest of the finished product but also because the process demands it. Misalignment results in uneven heating of the ends of the workpieces and telescoping or sliding of one piece over or on the other. On thin extended sections or shapes this is prohibitive. Nonferrous demands closer alignment than ferrous materials because the nonferrous has relatively less strength and is much more liable to telescope when hot. Ferrous materials will permit relatively wide-platen opening to accommodate work shapes in clamps and still resist telescoping. Nonferrous demands relatively narrow-platen opening and, thereby, more accurately cut work lengths.

Work must be aligned in the dies before the weld is made and alignment must be maintained by the machine through to the finished weld. This means that not only dies but platens on which dies are carried must be accurately aligned. Furthermore, the platen motion must be truly on the same center line as the stationary platen. The machine components, particularly the work holding clamps, must be substantial and designed to withstand the upset forging forces of the push-up mechanism without noticeable deflection. The thinner or more extended the work section, the closer the machine tolerances become.

When the work is ferrous, the dies must be copper or copper alloy in order to prevent the work from adhering or welding to the dies themselves. Premium yellow-metal alloy inserts are placed in the dies to help maintain life and alignment of the work. Most nonferrous materials may be held in steel dies, thereby permitting much greater die life and maintained alignment. These steel dies should be copper plated or tinned to prevent rusting and to assure good electrical contact in the secondary circuit. Either steel or copper-alloy dies may be water cooled, but the fitting up of the cooling circuit in replaceable dies is a nuisance and avoidable. High-production dies should be made easily replaceable and as simple as possible and still have sufficient physical strength. These dies should be mounted either on intermediate blocks or directly on the current-carrying platens. Either the blocks or platens or both should be adequately water cooled and designed to withstand the thrust of the die-holding screws. When the platen motion of the welder is properly designed for welding nonferrous the final die opening or spacing may be very small. In development of proper platen motion and narrow die spacing, "pinch-off" dies were developed. "Pinch-off" dies permit as little as 0.005- to 0.015-in. final die spacing and pinch the upset metal to a point where it falls off or is readily knocked off. The pinch-off dies not only facilitate the removal of the upset metal but also improve the welding technique and permit more consistent welding of materials usually difficult to weld. The narrow final die spacing produces a very narrow weld zone and very little heat-affected zone adjacent to the weld. High-tensile heat-treated aluminum alloys may be flash welded with relatively little loss in strength compared to the heat-treated condition. Leaded brasses may be flash welded with acceptable production strengths. Copper is welded to aluminum with only 0.0005-in. thick weld plus heat-affected zone.

F. L. Brandt is with the Thomson Electric Welder Co., Lynn, Mass.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.



Figures 1 to 5

Machine Setting and Results

	Work	Size, in.	Die spacing, in. Initial	Final	Flash-off, in.	Up set, in.	Current Cutoff, cycles	Flash time, sec.	Secondary Volts	Max current amperes	Static upset force Initial, lb.	Delay	Final, lb.	Work overhang in dies	Dies Copper	Steel	Pinch off	Tensile, lb.	Photo	Micro	Remarks
1	*Copper* to 28O *Aluminum* tubing	1/8 O.D. x 0.06, wall	37/64	1/64	3/16	3/32	5	1 1/2	4	16,000	1,500	8 cycles	2600	1/16 copper, bal. al.	..	X	X	13,000	Fig. 1A Fig. 2	Fig. 1	Less than 1% rejects in production
2	28O *Aluminum* tubing to itself	3/8 O.D. x 0.06, wall	37/64	1/64	3/16	3/32	2	1 1/2	4	15,000	2,500	....	..	Equal	..	X	X	13,000	Fig. 1B	...	Good commercial quality
3	*Copper* tubing to itself	3/8 O.D. x 0.06, wall	37/64	1/64	3/16	3/32	2	1 1/2	5	20,000	2,500	....	..	Equal	..	X	X	31,000	Fig. 1C	...	Good commercial quality
4	Miter 63S *Aluminum* window "Z" section	0.5 sq. in.	41/64	1/64	3/8	1/8	2	2 1/2	6	30,000	10,000	....	..	Equal	..	X	X	....	Fig. 3	...	Good commercial quality
5	Miter 63S *Aluminum* window "U" section	1 sq. in.	1	3/16	3/8	3/16	3	5	10	50,000	20,000	....	..	Equal	..	X	..	....	Fig. 4	...	Good commercial quality
6	*Aluminum* bars 14ST6 to itself	3/4 x 1 1/2	1 1/2	3/8	3/16	3/16	2	2 1/2	5	33,500	12,000	....	..	Equal	..	X	..	56,000	....	...	Aircraft quality
7	*Aluminum* bars 75ST6 to itself	3/4 x 1 1/2	1 3/8	13/16	3/16	1/4	2	3	5	33,500	12,000	....	..	Equal	..	X	..	62,500	Fig. 1E	Fig. 6	Aircraft quality
8	*Magnesium* rods FS1 to itself	1/2 diameter	1 3/32	3/32	3/16	3/16	4	4	3	14,000	2,200	....	..	Equal	..	X	..	39,000	....	Fig. 9	Aircraft quality
9	*Magnesium* rods M to itself	1/2 diameter,	3/16	1/16	...	...	*Controlled*	*butt*	*upset* 3	14,000	2,200	....	..	Equal	..	X	..	22,000	....	Fig. 8	Good commercial welds
10	*Copper* to FS1 *Magnesium*	1/2 diameter	1 3/32	31/32	3/8	3/16	4	2	4	16,000	2,200	....	..	1/8 copper, bal. mag.	..	X	..	26,500	....	Fig. 10	Good commercial welds
11	*Titanium* to itself	3 x 3/16	7/8	5/16	3/8	3/16	5	4	5.6	25,000	6,000	....	..	Equal	X	..	..	116,000	....	Fig. 11	Aircraft quality
12	Sterling *silver* to itself	2 x 0.105	13/16	1/8	3/4	3/16	2	3	8	38,000	9,000	....	..	Equal	..	X	..	....	....	...	180° bend test also cold rolled
13	Leaded *brass* (31/4%) to itself	0.325 diameter	1 1/16	1/16	1/8	1/8	8	4 1/2	6.5	25,000	7,000	....	..	Equal	..	X	X	45,000	Fig. 1E	a...	Good commercial quality
14	*Aluminum* rods alclad 56S	1/2 diameter	1	1/4	3/16	3/32 x 3/32	20	5	4	16,000	1,100	0.1 in.	2600	Equal	..	X	..	....	....	...	Drawing mill to 0.013 in.
15	*Tobin bronze* to itself	1/2 diameter	13/16	1/8	3/8	3/16	6	2	5.5	20,000	2,200	....	..	Equal	..	X	..	68,000	Fig. 5	...	Good commercial quality
16	*Copper* sheets to itself	0.08 x 10	1 1/8	3/16	3/4	3/16	8	6	10	60,000	22,000	....	..	Equal	..	X	..	....	....	...	Cold rolled to 0.040 in.
17	(72) *Manganese* (18) *Nickel* (10) *Copper* to itself	6 1/2 x 1/8	3/16	1/8	3/16	1/8	5	4	5	20,000	19,000	....	..	Equal	X	..	..	....	....	...	Bend and cold-roll test
18	(10) *Nickel* (20) *Zinc* (70) *Copper* to itself	6 x 1/8	1/8	1/8	1/8	1/8	5	4	8	35,000	9,000	....	..	Equal	..	X	..	....	....	...	Bend and cold-roll test
19	Yellow *brass* to itself	1/2 diameter	15/16	1/8	3/8	3/16	6	2 1/2	5.5	20,000	2,200	....	..	Equal	..	X	..	47,500	Similar to Fig. 5	...	Good commercial quality
20	63ST5 *Aluminum* to itself	2 1/2 x 0.125	37/64	1/64	3/8	1/4	3	3	6	30,000	12,000	....	..	Equal	..	X	X	27,500	....	Fig. 12	Good commercial quality

"Pinch-off" dies are made by releaving or cutting back at an angle on the faces of the dies that face each other across the platen opening. The releaved portions of the dies should be inserts that may be dressed or replaced periodically on production. Furthermore, the "pinch-off" portion of the dies should be a premium steel. Extreme care must be used in die- and welding-machine design to prevent the pinch-off die edges from striking each other and completely eliminating their usefulness. (Production life—up to 40,000 welds before dressing.)

In order to apply "pinch-off" dies, the flash welding machine must be very closely controlled. The flashing and upset motions must be precisely repetitive and to a point where the knives of the pinch-off dies never touch but finally come to the rest with approximately 0.015-in. spacing. If the welder deflects consistently and only a small amount, the deflection may be compensated for in the original setup. This deflection may be permitted up to a point where misalignment of the work occurs to the extent of producing faulty work or faulty welds.

In flash welding two different nonferrous materials such as copper to aluminum, coated materials such as Alclad 56S aluminum rods and "bleeding" alloys of copper such as leaded brass—a dual-pressure upset arrangement contributes to consistent high-strength welds. This dual pressure is designed so that the cutoff of current may be adjusted from a short time (a few cycles) before the first upset to a short time after the second upset.

Both of these upset pressures must be individually adjustable. When these difficult-to-weld combinations are flash welded in the conventional single-upset-force manner, the weld is not only "cold shot" and

full of oxide, but is very apt to have longitudinal cracks. Round rods look like a saw and the metal is brittle and coarse grained. In dual-pressure welding, the flashing action is snuffed out by a relatively fast moving, low-force, intensity upset. This low force and high current is maintained a few cycles (60 cycles reference timing) and then heavily forged. The flashing heats a narrow band on the ends of the workpieces, the first upset smothers the flashing and prevents oxidation. The upset current permits the heat to flow back in the workpieces and prevents the work from being "cold shot" on final upset. If welding conditions are not correct, the work may burn in two during the initial upset period.

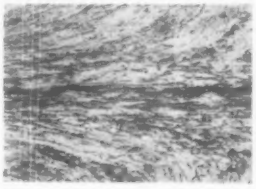


Fig. 6 Bond between alclad 75S-T6 alloy. Etchant: Kellers 100 × reduced 50% in reproduction

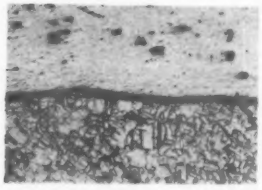
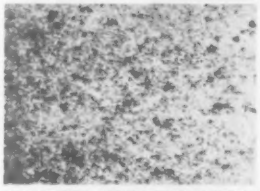


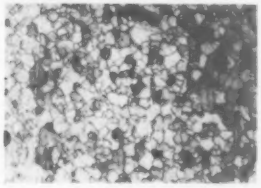
Fig. 7 Copper to aluminum (lower half). 100 × reduced 50% in reproduction

Several nonferrous materials and combinations of materials have been welded and the procedure developed to permit practical application. The welding conditions are reported in the accompanying table and reference is made to descriptive information. Air-operated flash-welding machinery was used throughout the work and the control consisted of an ignitron tube

Cross section showing flow lines and extent of heat-affected zone. 2 ×



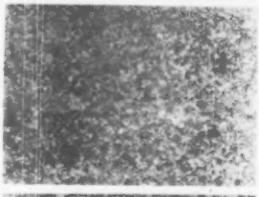
Weld junction showing recrystallized fine-grained material and absence of any inclusions, defects or cast metal. 250 × reduced 50% in reproduction



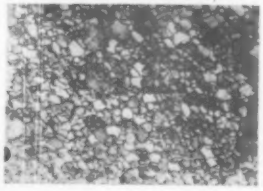
Base metal. 250 × reduced 50% in reproduction

Fig. 9 Micrographs of FS-1 alloy flash weld. Etchant: acetic picral

Cross section showing the junction and heat-affected zone. 21 ×



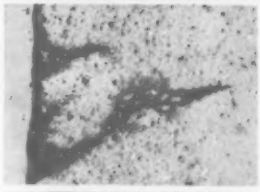
Weld junction showing recrystallized fine-grained region and the absence of any oxide, defect or cast metal. 250 × reduced 50% in reproduction



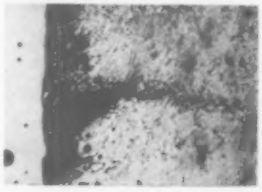
Base metal. 250 × reduced 50% in reproduction

Fig. 8 Micrographs of M alloy flash weld. Etchant: acetic picral

FS-1 top; copper bottom. 2 ×



Weld junction with copper at left. The Mg-Cu eutectic penetrated into the Mg to about 0.05 in. No evidence of penetration into copper. 100 × reduced 50% in reproduction



Weld junction of higher magnification to show intergranular penetration by the eutectic 250 × reduced 50% in reproduction

Fig. 10 Micrographs of FS-1 to Cu flash weld. Etchant: acetic picral

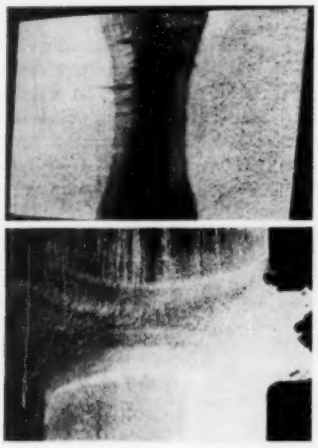


Fig. 11 Macro on longitudinal section — titanium weld. 5 × Etchant: HF-HNO_3-Glyceregia

contactor with 200% auxiliary-load resistors. All welding currents are full wave and cutoff is made by an adjustable mechanical multiplying device.

Wherever possible the material to be welded is in the annealed state. Nonferrous materials usually have relatively low electrical resistance as compared to ferrous materials and therefore, require high-power demands. There are several ways to reduce this demand during the upset forging period and not seriously affect the weld quality. Power-factor correction and three-phase converters (rotary or tube type) have been successfully applied but at great expense. The old idea of a reactor is being revived with the new addition of direct current for adjustment of saturation. The adjustment of saturation permits adjustment of the upset-current without affecting the flashing period. This not only reduces the power demand but also reduces the heating in the weld after the upset forging has occurred. Many nonferrous alloys show their best welded strength when the weld zone is narrow and the heat-affected zone is narrow. Although none of the tabulated welding conditions were made with a saturable reactor—many of them can be.

Figure 12 shows the actual oscillograph in the upper right and its enlarged calibration in the body of the figure. Note the pinch-off effect and four successive upset current periods before cutoff (half-cycle variation). The platen motion exhibited by this oscillograph is ideal for flash welding nonferrous materials.

This experimental work indicates that the required upset force should be in the vicinity of two-thirds the tensile strength of the parent material. In general, this rule applies to aluminum and its alloys and copper and its alloys. The static upset forces given in the table indicate dynamic forces in the vicinity of 150% when welding nonferrous materials on flash-welding machinery having suitable platen motion and control of the variables.

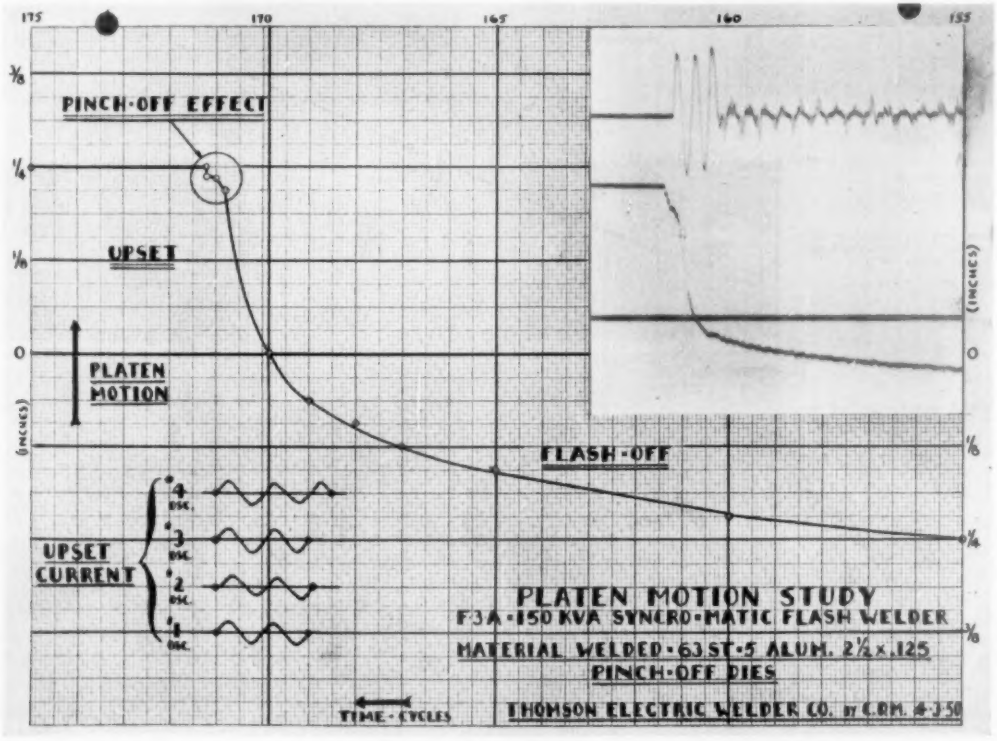


Figure 12

"Heliarc" Welding in Production

Developments of inert-gas-shielded arc welding in production applications in an aircraft plant based on economy of equipment quality, ease of fabrication, uniformity and lowered costs

by T. E. Piper

HISTORICAL SUMMARY

NECESSITY was the mother of Heliarc welding. Magnesium, the earth's most abundant metal and the most nonstrategic aircraft fabricating material of today, had been developed to the point where it could be launched on an important career in industry. Ten years ago John K. Northrop, President of Northrop Aircraft, Inc., with his characteristic foresight into the future of aircraft design, saw the possibilities of magnesium as a material for aircraft construction. Realizing that a successful method of joining was a prerequisite to the success of adapting the material to aircraft, he conceived and instigated the development of monatomic inert-gas-shielded arc welding. The cooperative efforts of engineers, technicians and shop personnel of the Northrop group produced the Heliarc welding process in the spring of 1940, which opened the door to unlimited development in fabrication of magnesium alloy airframe assemblies. Figure 1 shows the XP-56 airplane, an all-welded magnesium airplane constructed, designed and built to heliarc weld-fabrication methods.

Heliarc welding is an arc-welding process wherein the electrode, arc and molten metal are shielded from the oxidizing atmosphere by an envelope of monatomic inert gas which flows from an orifice in the torch. This inert gas prevents the formation of oxides in the molten weld metal, eliminates the necessity of using flux and reduces the accumulation of heat around the weld, thereby allowing better fusion and penetration and less distortion than is possible with ordinary arc welding. The elimination of flux removes the danger of flux inclusion in the weld metal. Flux inclusions occur to a large extent in other types of fusion welding and cause so much corrosion in magnesium welds as to make welding of magnesium with flux unsuitable for use in aircraft. The improved fusion and penetration possible with this method of welding produces joints of greater and more uniform strength, thereby permitting higher design allowables.

Fig. 1 The Northrop XP-56

An extremely advanced pusher-type tailless pursuit plane, was the first all-magnesium airplane and the first all-welded airplane ever built. Engineers designed a light but strong structure using almost no aluminum or steel parts—a development of great strategic importance. Completely "buried" engine installation drove twin counter-rotating propellers located behind the streamlined nacelle

GENERAL PRODUCTION APPLICATION

Ten years have elapsed since the Heliarc process was first tried and proved in production welding at Northrop. Although developed principally for magnesium, research laboratories soon found that all metallic alloys and many elements such as titanium can be most satisfactorily welded with this process. All ferrous, alloy-steel, copper, nickel, aluminum and super-alloys are welded satisfactorily by this method today.

As shown in Fig. 2, the original torches were air cooled and were developed around d.-c. generating equipment. Using this type of torch the process was definitely hampered because the torch capacity and service life were limited. Therefore, as research technicians and manufacturers tried other materials, the need for a water-cooled torch and other types of electrical equipment were developed to overcome these limitations.

As the water-cooled torch was being developed the a.-c. type transformer was also being investigated as a welding-current supply. With the use of a.-c. current some method had to be introduced to initiate and maintain the arc; therefore, high-frequency current was superimposed on the welding current to supply a path for the a.-c. current. Note Fig. 3.

T. E. Piper is Chief Process Engineer, Northrop Aircraft, Inc., Hawthorne, Calif.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

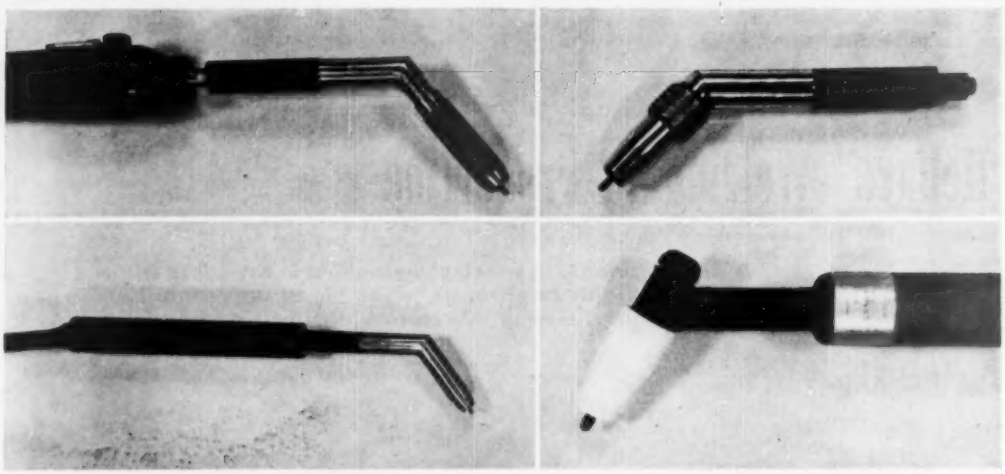


Fig. 2 (Upper left) Shows early developed air-cooled Heliarc torch. (Lower left) Air-cooled torch for use in restricted assemblies. (Upper right) One of the first manufactured air-cooled torch. (Lower right) The present Heliarc water-cooled torch design

Since a.-c. high frequency was introduced, the process has revealed many advantages for welding thin-gage corrosion-resistant steel which is also desirable for the welding of all gages of aluminum.

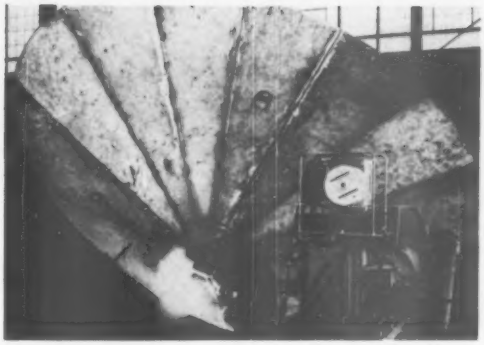
A welding engineer of a large manufacturing concern fabricating refinery equipment stated that when difficult welding conditions are encountered they usually turn to the Heliarc process to facilitate production welding. This process has become more useful and versatile than the other types of welding because (1) equipment cost is moderate, (2) automatic equipment producing superior results using continuous wire feed is available for corrosion-resistant steel and aluminum, (3) use of flux is eliminated, (4) warpage is reduced, (5) weld quality is better and more uniform, (6) grinding costs are considerably less.

Most small fabricators and manufacturers have d.-c. welding machines and the Heliarc equipment may be added without a large investment. Thus the designer and welding operator have available combinations of

Fig. 3 D-C and A-C electric welding equipment with a water-cooled torch. Continuous current control is possible for both types of equipment with the foot units shown on the floor

Courtesy of Southwest Engineering Co.

Fig. 4 Brass tube bundle heat exchanger for oil refinery equipment



Courtesy of Southwest Engineering Co.

Fig. 5 Large stainless-steel cone assembly-tank cover fabricated for the oil refinery industry

Automatic inert-gas metal-arc equipment

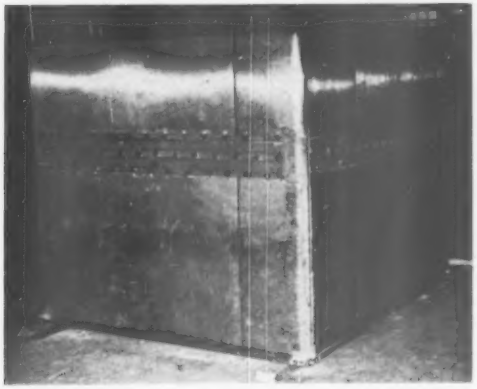
welding processes to select from, employing the same electrical equipment for metal arc and inert-gas metal-arc welding. This is also true for a.-c. welding machines which are designed for the Heliarc torch. Having a choice of various processes for fabrication the most economical procedure is possible by incorporating metal-arc, inert-gas arc welding or both when necessary.

In Fig. 4 is shown a tube-bundle heat exchanger for use in oil refining. The operator is welding a $^1/_4$-in. thick brass angle $1^1/_4$ in. wide to $^1/_{16}$-in. brass sheet. The Heliarc process is used in this instance because of the time saved by eliminating the use of flux. Also, a better quality weld is produced by eliminating porosity and flux inclusions.

A combination of Heliarc and metal arc welding is shown in Fig. 5. This is a cover of corrosion-resistant steel storage tank fabricated for a large refinery. The cone assembly is 20 ft. in diameter made of $^1/_4$-in. Type 316 corrosion-resistant steel. The triangular sections are welded with automatic Heliarc welding unit. Welding speed is 30-in. per minute. Approximately 50% saving in time is shown for this automatic equipment in comparison with metal-arc welding. Here again with the elimination of flux, the weld quality is appreciably improved and considerable savings result.

The dairy- and fruit-processing equipment manufacturing companies are using increasing amounts of corrosion-resistant steel. A 960-gal. milk vat is shown in Fig. 6. This unit is fabricated of 0.109-in. thick Type 302 corrosion-resistant steel. All joints on the sheet stock except the last corner weld are joined with an automatic Heliarc unit using a special holding fixture. The flat sheets are butt welded, the weld removed from the inside surface and then formed to the correct contour. The hat section at the middle of the unit is Heliarc spot welded. Formerly holes were drilled in the center of the hat section and tack welded and rosette welded with the metal-arc welding process. With the use of the spot welder considerable drilling time is saved and flux removal is eliminated.

Heliarc spot welding is a method of making small, localized fusion welds from one side of two lapped pieces of metal. The heat for making the weld is produced by



Courtesy of McHale Manufacturing Co.

Fig. 6 Corrosion-resistant (302) steel milk vat manufactured for the milk industry

Capacity 960 gal.

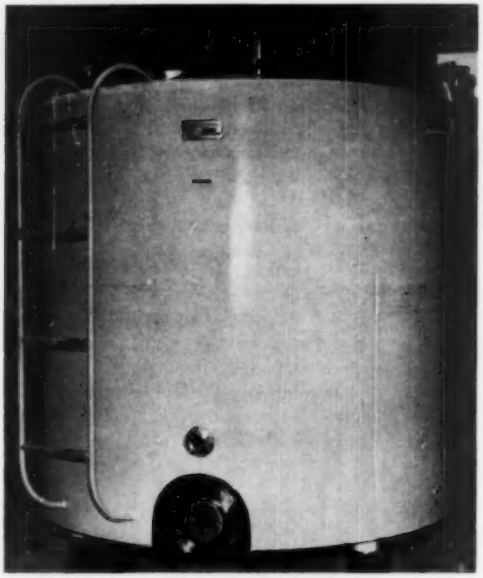
Courtesy of Virtue Bros. Mfg Co.

Fig. 7 Heliarc spot-welding application for fabricating chromium-plated steel chairs

Welding performed on the plated tubing with a small $^1/_{16}$ in. steel filler at the joint

an electric arc between a tungsten electrode and the work. The fundamental principles of spot welding are the same as for the Heliarc process generally in that an inert gas protects the weld puddle and the electrode from contamination. Welding action is controlled by the current input to the arc and the time the arc dwells on the work. Figure 7 illustrates an application of this spot-welding process.

Another milk-storage tank is shown in Fig. 8. The outside shell is fabricated of mild steel with the longitudinal joint welded with an automatic Heliarc unit.

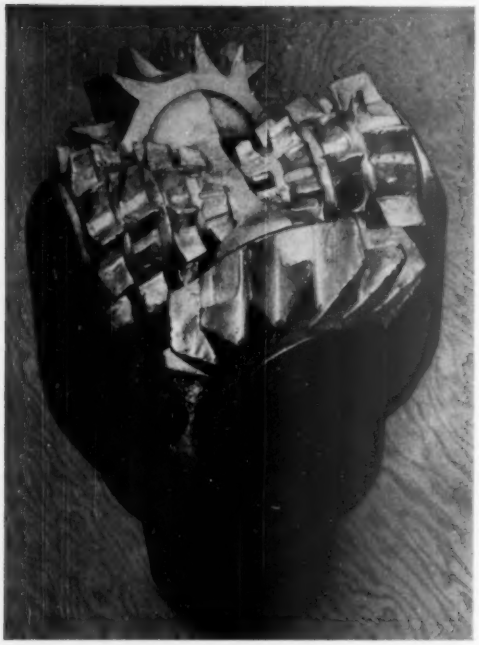


Courtesy of McHale Manufacturing Co.

Fig. 8 Heliarc-welded milk storage tank fabricated of low-carbon steel and 302 corrosion-resistant steel

Courtesy of Southern Pacific Co.

Fig. 9 Heliarc-welded Everdur water tank used on railroad coaches



Courtesy of Security Engineering Co.

Fig. 10 Teeth on this oil drilling tool bit are hard faced with the Heliarc process

Part is partially submerged in water while welding and in conjunction with the concentrated heat, prevents heating the internal bearings

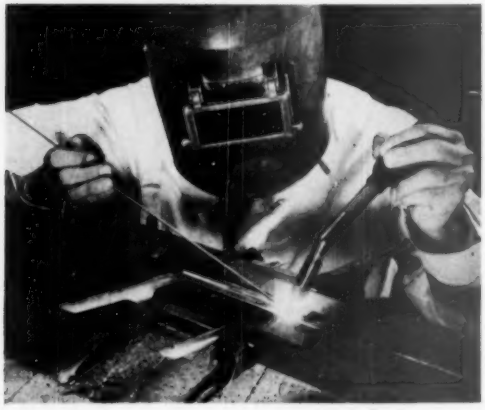


Fig. 11 Manually welding with an Air-Cooled Heliarc torch

Courtesy of Vic Pastushin Industries

Fig. 12 Manual and automatic Heliarc-welded 3S aluminum expendable aircraft fuel tank

The inside shell and external fitting are made from 302 corrosion-resistant steel. The inside longitudinal joint was welded with the automatic unit also.

Application of the Heliarc process as compared to other welding methods for the above units eliminates porosity and reduces grinding time on the welds, for all inside surfaces, which must be smooth to facilitate cleaning in order to prevent milk contamination.

The railroads have many applications for the process. They weld corrosion-resistant steel water tanks, window frames and Everdur water tanks. Figure 9 shows a tank fabricated of 16-gage Everdur alloy which would have been difficult to weld by other processes due to warpage and porosity. D.-C. Welding current, argon gas and Everdur rod was employed for welding.

Shown in Fig. 10 is an oil-drilling tool bit which is hard faced using the Heliarc process. The part is partially submerged in water while welding and with the concentrated heat, prevents heating the internal bearings on which the cutting units rotate. A carbide-type hard-facing rod is welded on the 4812 alloy cutting teeth. The supporting yoke is 4815 alloy material.

AIRCRAFT PRODUCTION WELDING

Foremost in engineering design considerations is the proper selection of materials and their structural form for the intended application. This selection depends upon suitable physical characteristics to resist imposed stresses, corrosion, adaptation to processing, procurement and ability to respond to methods of quality control. The manufacturer's reputation is entirely dependent upon the adequacy of controlling the quality of production processes in properly designed parts. The welding processes are of foremost importance in the metal fabrication industries of today. The Heliarc welding process is less fatiguing to the operators than the other methods of welding, resulting in higher average production-weld quality. Figure 11 illustrates the operation of the Heliarc process.

Since economical efficiency of the product must be achieved by designing to the very limit of the capacity and endurance of the product as a whole, the performance of a structural part is governed not only by one or two of its physical properties but by a combination of several of them together with the function of that part and its useful life.

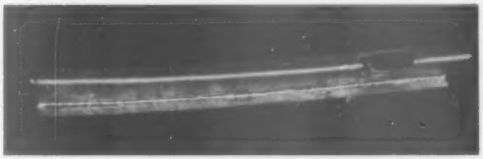


Fig. 14 Heliarc welded 61SW aluminum hot-air duct assembly for an airplane windshield

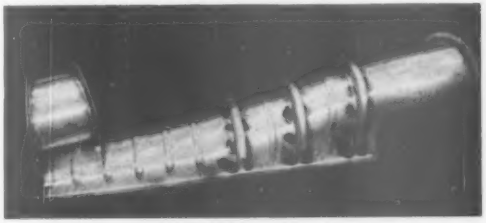
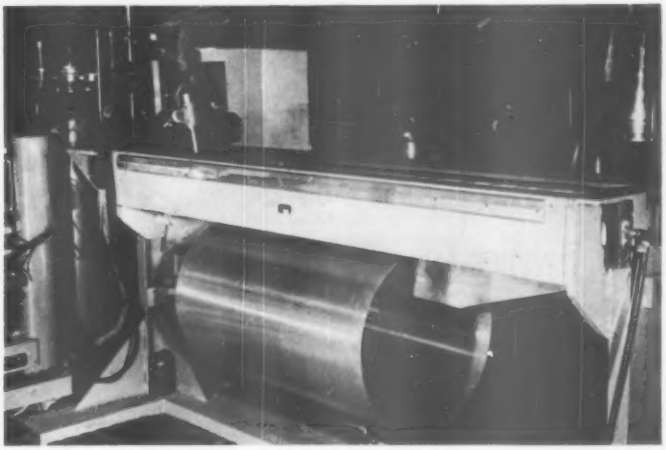


Fig. 15 Airplane air-duct assembly fabricated of 347 corrosion-resistant steel



Courtesy of Vic Pastushin Industries

Fig. 13 Holding fixture for automatic welding longitudinal butt weld on aircraft fuel tank

Welding, as defined by the AMERICAN WELDING SOCIETY is the "localized intimate union of metal parts in the plastic or plastic and molten states with the application of mechanical pressure or blows, and in the molten or molten and vapor states without the application of mechanical pressure or blows," applies to all forms of welding whether the metal is heated in a forge fire, by an inert-gas arc, or by a gas torch. The construction of modern aircraft employs all types and methods of welding to join the many thousands of parts and raw stock pieces required for the

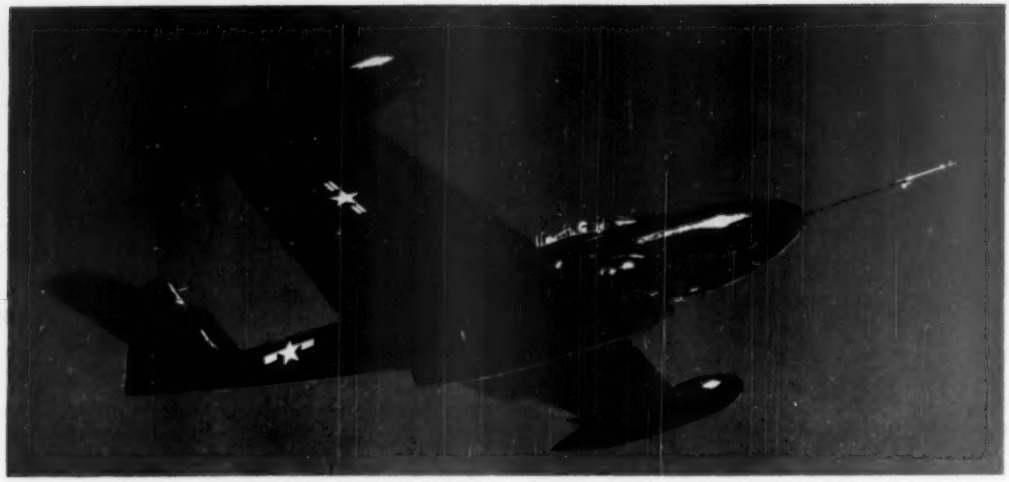


Fig. 16 This flight photo of the Northrop Scorpion XF-89, the Air Force's high speed "blue ribbon" experimental all-weather interceptor, shows the XF-89 climbing "upstairs" on a test flight from Edwards Air Force Base

Equipped with eerie X-ray "eyes" that enable it to penetrate darkness, fog and storms, the XF-89 is the prototype of more than 100 F-89 interceptors to be built for the Air Force by Northrop. The XF-89 placed first in an Air Force design competition for all-weather fighters. It is powered by twin jet engines and is manned by a crew of two, pilot and radar observer. Heavier, but slightly smaller than the Northrop Black Widow F-61 night fighter, the Scorpion has a wing span of approximately 50 ft. It is about 50 ft. long and 15 ft. high. The design gross weight is over 30,000 lb. The cockpit canopy is power operated, and ejection seats are provided for emergency bail out

savings of weight that is of primary consideration even at the expense of some complications in design or manufacture. The safety of the airplane and personnel are entirely dependent upon the materials used and the manner in which they are joined.

Automatic Heliarc welding of aluminum is being applied to an advantage as illustrated in Fig. 12. This assembly is an expendable aircraft fuel tank. The material is 3S0 aluminum 0.064 in. thick. Both manual and automatic Heliarc equipment is used with a.-c. high-frequency welding transformer. All longitudinal seams and circumferential joints at the center section are welded on holding fixtures which accommodate automatic units. The formed tips and fittings are manually welded. The assembly is welded as three units and bolted at the center section as shown. Figure 13 shows the fixture and automatic welding unit for welding the center section of the tank illustrated in Fig. 11.

The Northrop Scorpion XP-89 airplane, Fig. 16, contains many structural Heliarc-welded parts typified by 61SW aluminum hot-air ducts, Fig. 14, and stainless-steel air ducts, Fig. 15.

Acknowledgment is due The Linde Air Products Co. for its contributions toward the development of the valuable production facility the Heliarc process is today.

In conclusion, it can be said that the foregoing illustrations point out the significant advances in the science of welding of parts with greater facility and higher quality than would have been attainable without the Heliarc development.

Current Welding Literature

(*Continued from page 717*)

Welds. Distortion, L. L. Evans. New Zealand Eng., vol. 5, no. 4 (Apr. 1950), pp. 347–350.

Welds, Testing. Application of Resonance Vibration Method to Fatigue Testing of Spot Welded Light Alloys Structures, R. Weck. Inst. Welding—Trans., vol. 13, no. 2 (Apr. 1950), pp. 33r–38r.

Welds Testing. Butt Weld Testing with Hughes Supersonic Flaw Detector. Machy. (Lond.), vol. 76, no. 1959 (May 11, 1950), pp. 667–668.

Welds Testing. Preliminary Tests on Welded Connections, E. K. Frankl. Inst. Welding—Trans., vol. 13, no. 2 (Apr. 1950), pp. 27r–32r.

Welded Aluminum Ammonium Nitrate Prilling Tower

Equipment fabricated from aluminum 61-S-T6 to withstand severe service conditions involving strength, fatigue, corrosion and temperature changes

by H. N. Hockensmith

INTRODUCTION

METALS used in the Chemical Industry must satisfy rigid demands. In addition to possessing a quality of high strength and being able to resist vibration from adjacent operating equipment, they must be resistant to corrosion from the material being handled both in order to prevent the material itself from being eroded and also to minimize a possibility of contaminating the finished product. In addition, in order to keep maintenance costs low the metal generally must be able to withstand sudden temperature changes. Cost is of course a primary consideration. Aluminum 61-S-T6 sheet was selected as meeting the requirements for ammonium nitrate service in the Prilling tower and air ducts in the plant recently constructed by Brown & Root, Inc., for Phillips Chemical Co. in the Texas Panhandle. Ammonium nitrate solution (NH_4NO_3) used in this process is made up of nitric acid (NHO_3) and ammonia (NH_3). In order to form the solution into pellets it was necessary to erect an airtight aluminum 22 by 32-ft. rectangular tower, 155 ft. high. Two 75,000-CFM blowers circulate cold moist air upward through the tower contacting the solution which is sprayed into the tower as a fine mist from spray heads. These drops of solution freeze into prills while falling through the rising cold air. The prills are collected on a conveyor system, passed through dryers, coolers, mixed with clay and bagged. The finished product leaves the plant in 100-lb. bags of prilled ammonium nitrate fertilizer. In addition to this solution being extremely corrosive it also tends to freeze and collect on any surface while moist. The mirror-smooth surface of the aluminum sheets was a prime factor considered in its selection for this particular service. Some of the unique features of this job were brought about because the plant had to be complete by very early spring in order to meet the summer fertilizer market; in other words it was necessary to complete the tower as a winter job in a country noted for its high winds, dust storms and frequent extreme temperature changes.

H. N. Hockensmith is General Superintendent, Brown & Root, Inc., Dumas, Tex.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

ALUMINUM DETAILS

The structural steel framework on the tower was erected in a conventional manner. Six-inch steel channels spaced on 3-ft. vertical centers served as a means of attaching the aluminum wall sheets to the tower structure. The wall sheets were furnished to the job prefabricated by tack welding a vertical aluminum stiffener angle to one end of a cut sheet of 0.081-gage metal and by tack welding a horizontal angle $1^1/_2$ in. from the upper edge of the sheet. This angle was drilled to match the drilling in the channel iron girts. To prevent the solution from tending to collect on the tower lining the sheets were lapped downward (shingled). As furnished one ring was made up of 10 panels. The tower alone therefore contained 10 full-height vertical butt seams and 43 horizontal lapped seams. Five-eighth-inch stainless steel machine bolts were used to secure the aluminum angle to the channel iron girts. The designers, in order to prevent the setting up of a galvanic cell by contact of the aluminum with the carbon steel, provided a $^1/_8$- by 3-in. gasket to be placed between the aluminum angle and the girts as shown in Fig. 2. The airtight aluminum liner was formed by lapping the 39-in. wide panels 3 in. and making a continuous inside weld. The specifications called for a continuous outside weld but this was considered superfluous by the owners, who decided that a 2-in. bead on 12-in. centers was sufficient. The entire job, including the return air duct, required approximately 10,000 ft. of welding.

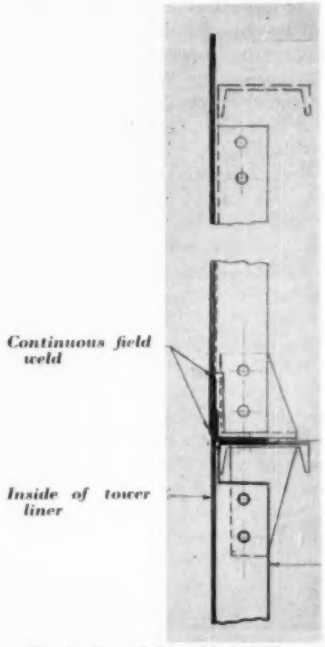
This 3- by 22-ft. rectangular aluminum duct was designed to follow the general pattern used in the tower proper, the principal difference being that prefabricating had been carried one step further by shop welding the horizontal seam between two 3-ft. panels. The number of field welds were materially decreased but the

Fig. 1 Completed aluminum prilling tower

fit-up was made more difficult. The duct adapted itself readily to being assembled on the ground in five 20-ft. lengths weighing about 3 tons each including the support structure which was used as a ridged back-up frame after pulling it to true line with coffing hoists and jacks. Since shop conditions could be approached on the ground, the actual duct welding did not present a very great problem. Considerable time was lost, however, because the prefabricated sheets were necessarily slightly distorted. This portion of the job would have been simplified had the prefabricating been confined to tack welding angles and the balance, job assembled, where a complete ring of 3-ft. sections could have been completed before the hold-down clamps were removed.

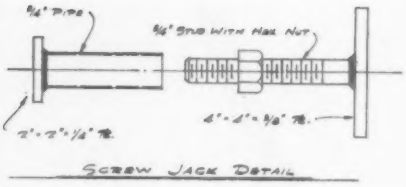
SCAFFOLD REQUIREMENTS

It was necessary for the working scaffold to satisfy several requirements besides being fairly simple to move. The main platform consisted of a plywood deck supported on welded pipe trusses. Old gasket material was used to seal off the updraft between the platform deck and the tower liner. Stability was achieved by mounting 8 rubber-tired wheelbarrow wheels on a simple screw arrangement and spacing them evenly around the platform perimeter. This arrangement also prevented the wind from drifting the platform to either side. A service elevator was operated through a 6-ft. square opening in the center of the main platform. The addition of the smaller service elevator provided a simple means of supplying the work regardless of outside wind conditions. Both the main platform and the service elevator were operated by a gasoline-powered 2-drum hoist. The hazards of repeatedly raising the platform in 3-ft. lifts were reduced by securing safety lines to each of the four corner columns. Since the whole operation was dependent on being able to maintain a blanket of inert gas at the weld it was necessary to keep 3 or 4 complete rings of panels hung above the platform to act as a wind break. The actual tower welding therefore was performed in a 20- by 30-ft. rectangular room about 12 ft. deep. An adjustable system of hold-down bars (Fig. 3) was anchored to the platform deck to minimize sheet distortion. These



Heavier lines field welded—lighter lines shop welded

Fig. 2 Aluminum steel: typical wall section



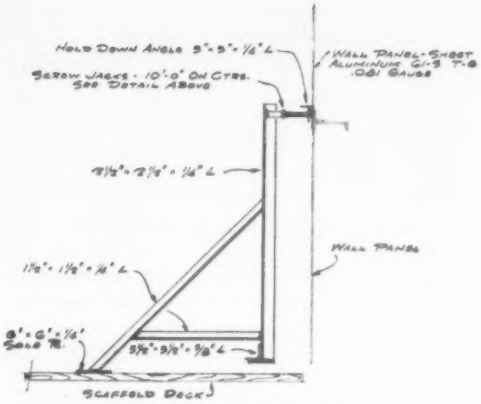


Fig. 3 Hold-down bar detail

bars were required although Heliarc's highly concentrated heat naturally tends to reduce distortion. The platform was also equipped with four floodlights. In this way it was possible to accomplish nearly as much work on the night shift as was done during the day. Generally the outside temperature was lower at night but this was offset normally by a drop in wind velocity.

GENERAL PROCEDURE

Tower wall panels were field welded with 4 Hi Frequency A.-C. Transformer type welders, rated at 200 amp., with 100% duty cycles, equipped with an automatic solenoid argon cutoff valve and time relays. One of these relays is adjusted to allow gas coverage at the torch 5 sec. before the weld melt is actually started. This protects the metal from the contaminating oxides that would be formed by starting the tungsten arc in the atmosphere. Another time relay is adjusted to allow a flow of argon over the tungsten for a period of 12 sec. after the welding arc is broken. This allows the tungsten to cool in a blanket of pure inert gas, thereby preventing the atmosphere from contacting the hot electrode. Although not absolutely necessary, this arrangement is highly desirable and will more than pay for the additional cost of this control panel by conserving the argon flow time to an absolute minimum, as well as reducing tungsten consumption. For nonautomatic operation, a simplified manually operated valve is available that is actuated by hanging the Heliarc torch on a control arm, thereby closing the argon flow when not in use. This arrangement is adequate for shop use. These four welding machines were placed at the four corners of the service elevator opening on the main scaffold. All aluminum panels were raised on the service elevator and buffed with a stainless steel brush of fine gage wire. This removed most oxides, dirt and grease particles that had accumulated in transit immediately before erection and welding. It was found that even the fine oily film left by the contact of human hands would develop trouble, as did the dust and sand that filled the air on a great many days. The oxide-forming foreign particles accumulated on the 43's filler wire were removed shortly before the wire was to be used by immersion in nitric acid followed by baths of caustic soda and water (Fig. 4).

The filler wire was cut in approximately 10-ft. lengths and coiled for convenience in handling before being cleaned. It is extremely important to have a clean surface, as well as clean filler wire in order to obtain an attractive, dense joint. The argon blanket effectively shields the weld puddle from contamination once the arc has been struck. A three-phase, 440-power circuit was installed to the full height of one of the corner columns providing current for the machines at any elevation. This arrangement of machines was highly satisfactory and had many advantages.

By locating the machines near the work, it was possible to use shorter length lead cables. This location made it possible for the welder operator to adjust the welding heat as required to suit varying wind and temperature conditions around the tower. It was found that a variation of as much as 30 amp. on the same type weld joint was necessary depending on whether or not the back side of the panel was exposed to the sun.

The argon cylinder and flowmeter were located adjacent to each machine making it possible for the welder to adjust the flow of argon. Gas conservation is important due to the relatively high cost by volume;

Fig. 4 Filler wire is coiled and cleaned

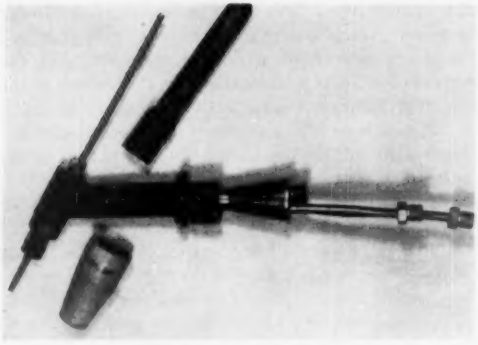


Fig. 5 Conventional HW-4 electrode holder

however, the cost per foot of weld need not be excessive.

The convenient arrangement of having the machines located on the scaffold would not have been possible if electric power had not been available. Actually the job was first started using gasoline-powered machines located on the ground but we experienced considerable down time due to cold weather, refueling and time lost due to the operator not being able to quickly adjust the heat to suit changing conditions. The gasoline-powered machines were kept in service, prefabricating pipe in the welding shop, but the transformer type were installed on the scaffold.

MODIFIED TORCH

Working under shop conditions the standard water-cooled Heliarc torch HW-4 proved to be very satisfactory; however, considerable lost production time was encountered when we attempted to use the torch exposed to extremely cold weather and necessarily rough handling. A field-designed air- and gas-cooled electrode holder eliminating the troublesome water hoses and fuse was fabricated by drilling a $^3/_{16}$-in. gas inlet hole through a $^5/_8$-in. bronze copper rod approximately 6 in. long. This was used as the torch body and resulted in its having a much heavier wall than the conventional torch. One end of the rod was upset and drilled to receive the 25-ft. section of No. 2 welding cable. The other end of the rod was beveled to fit the torch head which was made from a similar piece of rod, drilled and threaded to take standard Heliarc accessories. Connections were made with silver solder. Figure 5 shows the conventional HW-4 torch. The modified torch is shown in Fig. 6. The insulating handle has been removed from both torches. It was first thought that heat in the torch handle would be a major problem but currents as high as 200 amp. were used for entire shifts without the torch handle becoming excessively hot. Part of the heat is carried away by the argon gas flowing through the holder while the increased cross section of the torch body adds to its ability to dissipate the I^2R heat losses generated. It was not necessary to cool the No. 2 welding cable mentioned above. Roughly comparing

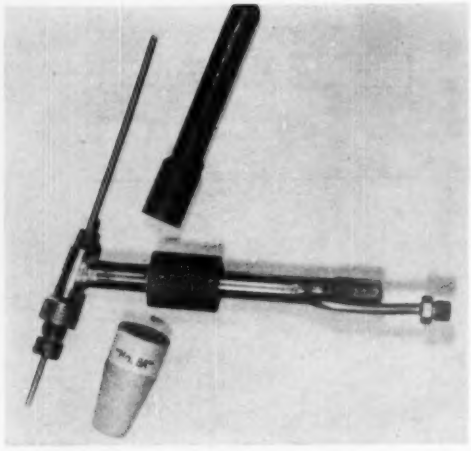


Fig. 6 Field modified electrode holder

the cables, 25 ft. of the standard lead cable carrying a current of 200 amp. must lose approximately 1000 watts through the circulating water while 25 ft. of the No. 2 cable used* must lose only 200 watts. This heat is readily dissipated by the atmosphere.

COST

Comparing field welding costs under conditions similar to those discussed here with production line shop cost would serve no practical purpose. The quantity of tungsten electrode, ceramic cups and gas used will vary considerably with the conditions under which the work is performed. We found, for instance, that the recommended five to six liters of argon per minute was adequate for shop welding when the work was protected from draft, but the volume had to be increased as high as six to ten liters per minute to work on the tower. Under some extreme conditions it was even necessary to skip short sections until the wind direction changed. Using 4 machines, the principal job was completed by finishing an average of $1^1/_2$ rings per shift or 48 ft. per man per shift. The actual welding then, using a welder and helper as a team at $2.25 and $1.50, respectively, makes the over-all labor cost per foot 66.6 cents. It must be realized that included in this cost is considerable labor time that is not a direct welding cost but covers the cleaning of the joints, fit-up and all down time due to weather, mechanical failure and the time required to move the platform.

ACKNOWLEDGMENTS

The author is indebted to the Phillips Chemical Co. for permission to publish this paper. I also wish to acknowledge the assistance of Bill Tucker, Welding Supt., Brown and Root, Inc.

* Size No. 2 AWG., 66370 CM, 7 x 7 x 35—No. 34 Stranding. D.-C. resistance is 0.196 ohm per 1000 ft. cable was chosen because of its flexibility and comparable current carrying capacity.

Welding at the Railroad Reclamation Plant

Economy of reclamation must be checked constantly as well as serviceability and safety. Examples of reclamation

by W. G. Muschler

WELDING at a Railroad Reclamation Plant carries with it many major responsibilities which, of necessity, are divided into the categories of reclamation and manufacturing.

RECLAMATION AND MANUFACTURING

Since reclamation can be applied to material used by every department of the railroad, we must decide if the reclamation means a saving to the railroad; will the reclaimed item serve as well as new material; will the reclaimed item meet A.A.R. and railroad specifications and requirements; is there a need for the reclaimed material?

The economy of reclamation is something the personnel of the reclamation plant must check constantly. If the cost of labor and material to reclaim an item, plus the overhead, less the value of the item, if sold as scrap instead of reclaimed, is higher than the cost of the new material, then the railroad would lose money by reclamation unless new material is unobtainable.

The proper place for a reclamation plant is adjacent to the scrap yard, because literally, "Thar's gold in them thar hills."

Reclamation means "to make a waste product useful." This can include converting or reworking or reshaping the waste material into something entirely different from its original form. Through the welding process many items of material are built up or welded to their original state of usefulness. Some are reclaimed many times, giving service as effectively as when originally purchased.

Welding also has another very useful purpose. A weak spot may be detected and by welding, it will be strengthened. In effect, this is a practical method of research which leads to an improvement in design.

The question of serviceability of the reclaimed item is very important. The using department has a right to expect the same life and good results from the reclaimed item as from new material.

The A.A.R. Interchange Rules and our own Engineering Specifications must be rigidly followed as they define the limits of welding processes. Therefore, all work at the reclamation plant is checked from those angles.

All reclamation of material is done on orders approved by the using department or, if for stock, by the storekeeper. Material is not reclaimed in advance of receipt of properly approved order, nor merely to keep the plant busy.

To the foregoing must be added the psychological feature. The user may be skeptical of using reclaimed material, so reclamation must be sold to each mechanic and officer, and the best sales talk is a product good in appearance as well as in quality.

Welding by all processes requires the utmost care and good judgment on the part of the welding operator. The operator's ability to satisfactorily perform the work in question, by the process selected, must be certified by the officer in charge, on the basis of the tests for qualifying welding operators as set forth in the *Welding Manual of Standard and Recommended Practice of the A.A.R.*

The welding operator's ability is primarily qualitative. He should not be blamed for failure if he is directed to weld or braze materials that do not lend themselves to fusion or adhesion, or to perform a job with the wrong process or materials. That is why the A.A.R. welding operators' qualification test is strictly on the basis of the operator's ability to control molten metal. I am sure that all welding operators are aggressively interested in making a perfect weld. That is their ambition.

As provided in the *Welding Manual*, the entire crack or fracture must be cut out with a cutting torch or chipped out or ground out for a sufficient distance so that no portion of the crack remains. The surfaces, upon which new material is to be deposited, must be clean and reasonably smooth. If the surfaces are prepared by flame cutting, the oxide scale must be removed before new metal is deposited.

A single pass is preferable in making the weld deposit in oxyacetylene welding.

W. G. Muschler is Superintendent of Reclamation, Burlington Lines, Eola, Ill.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

For arc welding, various procedures are acceptable. Multiple pass welding in layers of about $^1/_8$ in. thickness is desirable. Care is taken to avoid heavy reinforcement and abrupt changes in section thickness at the line of fusion. Excess metal must be dressed down to proper dimensions on built-up surfaces. Our practice in all possible operations is to position the work so as to weld downhand.

Proper heat treatment after welding is very important. Annealing, normalizing or stress relieving is done at a rate of about 500° F. temperature increase per hour, and then held at the specified temperature for 1 hr. per inch of maximum thickness of material.

For annealing, the temperature shall be 1500–1600° F., and material shall be allowed to cool to temperature of 500° F. or lower in the annealing furnace.

For stress relieving, the temperature shall be 1200–1250° F., and if done in furnace, the material shall be removed and allowed to cool in still air. This can often be done with the oxyacetylene torch by bringing the area to a red heat and allowed to cool in place.

Normalizing requires the temperature to be 1500–1600° F., and material removed from furnace and allowed to cool, protected from drafts and weather.

The most common metals used in railroad structures are mild steel, cast steel and malleable iron. Each of these materials requires the proper filler rod material to duplicate as closely as possible the physical properties of the respective materials to be welded, except, of course, the areas normally subject to abrasion, in which instance, a specific type of weld metal may be applied to reduce the rate of abrasion, thus prolonging the service life of the material.

Let us now review the typical welding procedures which are found in our reclamation plant.

Malleable Iron Freight Car Journal Boxes

The first step, and it is a very important one, is thorough cleaning by burning off the oil and refuse in the annealing furnace, using a low temperature, This is necessary to expedite a good sand-blasting job.

At this point, it seems desirable to explain by photograph the cycle of journal-box reclamation. Sand-blasting permits ready location of cracks.

Figure 1 shows the welding operator building up the wedge-seat surface. For building up areas subject to abrasion, $^3/_8$-in. bronze is used to provide a very hard surface. For welding cracks and fractures, $^1/_4$-in. bronze is used as it adheres very well to malleable iron and provides a strong weld. In welding malleable iron parts, it is mandatory to use the oxyacetylene bronze-welding process for making repairs in sections subject to tensile stresses. The amount of metal applied is accurately controlled, so that a minimum of grinding is required to bring the area to correct dimension. Figure 2 shows the grinding of the dust-guard surface. With the completion of the grinding operation, the reclaimed box is ready for additional years of service and a saving of approximately 75% of the purchase price is realized.

Figure 1

Figure 2

Figure 3

Another important item in use on the railroad is the machine-switch plate, as shown in Fig. 3. These are built up to original thickness by the use of 1/4-in. steel welding rod applied by oxyacetylene process. This rod provides a very hard-wearing surface which hardens further with use. Reclamation of this item saves approximately 80% of the original purchase price. Figure 4 illustrates reclamation of switch-stand bases, also an economical operation. Note that the part is held in a shop-made positioner that facilitates downhand welding. For this, we use 1/4-in. bronze. Figure 5 shows these switch stand bases before welding, as-welded and as-finished.

Figure 4

Figure 5

The manufacture of warehouse trucks provides the welding shop with a complete operation.

Figure 6 shows the oxyacetylene heating of "T" shaped warehouse truck member. This is one of four bends made on each truck. Metal is 5/16 in. thick, 3 in.

Figure 6

Figure 7

each way in the "T." Heating time with No. 80 tip is 15 sec.

Figure 7 shows roll bending by hand while corner is red hot. Jig is made for this job.

Figure 8

Figure 8 shows the arc welding of base members of a warehouse-truck frame on special-holding jig, using E6012 1/4 in. electrodes.

In the truck building program, Fig. 9 it was found economical to weld up small subassemblies. Here is the front swivel wheel in assembly jig prior to welding. Back-wheel assembly is made on the same jig.

Welding 1-in. pipe for end gates for warehouse truck is shown in Fig. 10. Jig will be seen underneath pipe the operators are welding. No. 40 tip is used with 3/16-in. mild steel rod. Welds are smooth and require no after finishing.

Warehouse truck—all-welded—prior to spray painting and application of wood deck floor Fig. 11.

There are three principal factors behind our construction of these trucks. First, some of the material was scrap. Second, we had sufficient qualified welders to do the work. Third, we had the facilities and space.

Figure 9

Figure 10

Building up worn surfaces of truck bolsters is permissible, provided the material remaining in the part is equal to 60% of the original section. Because there are no restrictions on welding cracks, or fractures (even if

Figure 11

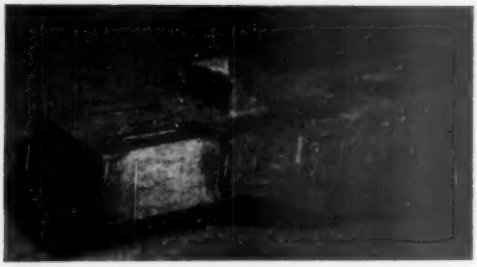


Figure 12

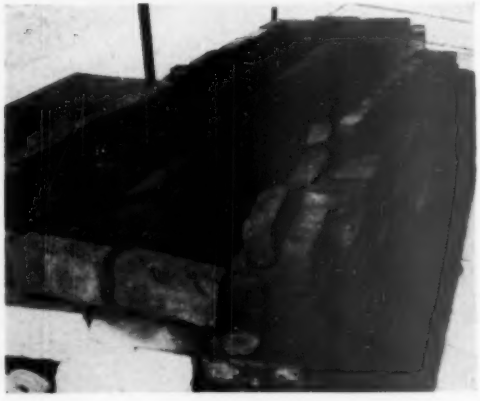


Figure 13

Figure 14

75% saving is realized on each drum.

Conventional Passenger Car Brake Beams

Figure 14 shows the welding operator building up the brake head set in a turning jig. For this purpose we use No. 60 tip.

Figure 15 shows two heads, one prior to welding and one welded after it is bored to dimension.

Figure 16 shows the built-up ends of brake-beam compression members. The oxyacetylene process is used for this work, the rod being 1/4- x 36-in. No. 1 rolled steel.

Figure 17 shows the outside circular cutting tool we devised for turning to proper dimension the built-up ends of brake beams.

Previously, we mentioned that in a railroad scrap pile there is to be found the equivalent of gold. Actually, we do find silver. Diesel piston-pin bushings are lined inside and outside with silver Fig. 18. The desilvering of the bushing is done by placing the bushing

Figure 15

Figure 16

Figure 17

broken entirely in two), an enormous saving of approximately 94% is realized, Fig. 12.

The preparation, welding, finishing, annealing, normalizing and stress relieving is governed by the same procedure as applied to other car parts.

For the purpose of building up bolsters, 3/16- and 1/4-in. electrodes are used; for welding cracks or fracture 1/4-in. E9010 electrode. This provides a tensile strength of 112,000 lb.

Cable Drum for Gantry Crane

These drums, as shown in Fig. 13, are cast iron, weighing 1,550-lb., 14 in. in diameter, 90 in. long with a grooved area extending 36 in.

It is obvious that such an article is too valuable to scrap and that replacement with a new article would cause serious delay.

The welding of such a casting required a mild preheat of about 700° F. Two hundred and fifteen pounds of 1/4- and 3/8-in. cast-iron rod was used in this building-up operation, using No. 80 tip.

The drum was then grooved. An approximate

in a cast-iron ladle and playing the oxyacetylene flame from a No. 80 tip on the bushing. Silver on both inside and outside melts off the steel core and flows into the ladle. Next step is to pour silver into a sand mold that provides 16 round slugs of silver of 99.9% purity. Silver on one bushing makes one slug.

Figure 19 shows a comparison of the size of the bushing and one of the slugs of silver sawed in half.

In conclusion, I would like to briefly describe our plant and force. The plant has a floor space of 4000 sq. ft. and is piped throughout for oxygen and acetylene. Oxygen is generated. The force totals 46 men, including 4 oxyacetylene welders and 7 arc-welding operators.

Figure 18

Figure 19

In conjunction with welding, the shop has blacksmith shop, tin shop and machine shop. Parts to be reclaimed are shipped into the shop from the entire system. Sorting of received materials and decision to reclaim is the responsibility of our employees.

Naturally much reclamation is performed that does not require welding. A truly amazing array of metal parts and items go through one welding process or another. I would say that the number of parts reclaimed by welding is around 175. These vary in size, type of metal and general condition.

The extent and type of reclamation performed varys widely on different railroads. Based on the work done in our shops that for years has resulted in important dollar savings, I would recommend strongly that other railroads, in the face of ever-rising costs, step up or introduce reclamation programs.

What Is Needed in the Professional Training of a Welding Engineer

The greatest need is to teach the young engineer how to think and keep on acquiring knowledge after graduation, and to develop in him the ability to use that knowledge

by John M. Parks

AN ENGINEER is one who applies knowledge and scientific methods so as to improve manufacturing procedures; a welding engineer is one concerned primarily with the application of welding to these procedures. There are other definitions but this will suffice. That one must be trained for this profession is obvious; the question resolves itself rather into what training is necessary or adequate, and this in turn depends upon exactly what a welding engineer is going to be expected to do.

Manufacturing operations have constantly placed greater demands upon welding as a fabricating tool. There were relatively few demands a generation ago; in the next generation, what is demanded today will likewise appear small. Today the demands of a given industry or organization for a welding engineer may be small or large; for example—he may be expected to be versatile and substitute for other engineers or he may be expected to be a specialist in some one of the many advanced applications of welding.

One thing is certain; he can not have too much knowledge nor too much ability, nor too much experience to achieve successfully his objectives. Furthermore, he must accurately know his limitations, know how to work with people, know when to call for help, know when to speak up, and when and how to remain silent. Life and the pursuit of happiness is a complex affair when we make it so; the welding engineer like all others must first solve this problem. How he may best be trained to accomplish this is a difficult but vitally important question and one worthy of considerable discussion.

One must be trained never to stop thinking and learning; college commencement is the transfer of a man from learning in academic halls to learning in the world of industry. Analysis of the product of our educational institutions indicates that many are lost in extending their academic training into this new world; they have become confused, bewildered and preoccupied in petty occupations or occupations which appear petty. As a result they stop the functions of learning. Sometimes they deliberately relax as a relief from the high-pressure studies of the engineering school which often has become so interested in stuffing knowledge down the throat of the engineering "bird" that incentive for learning is virtually destroyed. After four years of constant pressure, the student has but one objective; get that degree and run and never look back. The necessity for time to think is gone; it has been driven from his mind; the man is ready to turn a wheel and drive the mill with muscle rather than brain power. When, if ever, he stops running, he again is ready to start learning. He looks about for tools; what and where are they?

The dark ages of socialism and slavery were ended when men freed their minds and began to think. The printing press gave them the tools for further thinking; namely, other men's thoughts. Likewise, today the printing press brings to this man the tools for thought—a vast literature of science and engineering, the work of many minds and many hands, the right and wrong

John M. Parks is Supervisor, Welding Research, Armour Research Foundation.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., week of Oct. 22, 1950, Chicago, Ill.

mixed together for him alone to decipher. It is here that our welding profession should help; its technical articles with critical discussions by well-informed associates, its reviews of events in related engineering fields, its recommendations of books, and inspirational articles of what is known as well as what is not known. We should keep alive and expand the spirit of curiosity and inquisitiveness of man and things; we should turn not into the slumber of complacency, the death of scientific and technological advancement.

Here then are my brief recommendations for fulfilling the needs of professional training for a welding engineer:

To our educational institutions:

1. Teach basic principles of science and engineering; separate the variables and teach the fundamental relationships between man and matter.

2. Teach the student how to learn, how to think, how to teach and how to live in our complex industrial world.

3. Do not load the student with details, no matter how important; rather teach him how to learn, how to use the library, how to find the details, how to put them together and how to reason.

4. Impress upon the student the fact that pursuit of knowledge by thought and experiment is never done; therefore, give him time in his day to develop the processes of thinking—develop in him the desire to learn rather than to achieve grades or graduation.

5. Train your students to work together as a team of individuals—each retaining his individuality yet working cooperatively with his associates. Engineers are likely to handle material things well but fail to work with people.

To our profession:

1. Encourage our associates to read technical literature and think about the fundamental aspects of the welding processes which they are using. Encourage the asking of stimulating questions of speakers and experts; speak out and participate in our technical discussions.

2. Read critically and use the technical libraries—a few spare moments in the stacks is always well spent; it broadens one's perspective in related fields. Granted that three-quarters of the technical articles are not of much value—scan at least the few that are.

3. Question all concepts; there are no infallible experts in the welding field or elsewhere. Frequently, half truths are taken as whole truths. Classify your information into observations, postulates, theories and laws or rules; decide for yourself where each idea belongs. Remember repetition of an observation or thought by many mouths does not make it true.

4. Research and development are the activities which advance our understanding and knowledge; those that control the finances for these activities must spend them well and in such a way that further finances become more readily available. Costly errors can be made—not all research is well advised; therefore, assist in every way those that must make these important decisions of research policy.

Since the field of research and development is the realm of my activity, I would like to close these brief comments with what I consider necessary in a research and development man upon whose shoulders the responsibility of furthering our profession rests.

First, he must be well informed on the subject under study; that is to say, well informed as to the literature, the shop practice and the economics of manufacture as well as the labor and accounting practices that are sometimes unknown even to management.

Second, he must be of high intelligence with a keen observational ability and a high and carefully controlled curiosity.

Third, he must persistently pursue a problem in its many forms in order to separate the independent and dependent variables by putting them together experimentally in many different representative combinations.

Fourth, he must take time to think and analyze, yet spend time next to the experiment itself.

Fifth, he must understand and respect his associates; he must objectively live with his associates and their problems without emotion and hostile personality. He should criticize ideas and methods, but not people who are sincere in their beliefs. Likewise he should accept such criticism without malice.

Sixth, he should be a philosopher, cherishing the ideals of a free society of independent individuals confined in law.

With regard to his education, he should have a general engineering bachelors training, a masters training in welding engineering, a doctorate in one of the basic sciences, preferably physics or metallurgy and several years' experience in industry where he has had the opportunity to acquire an understanding of management and labor relations, accounting and materials handling, financing of new ventures and their evolutionary growth and last and most important of all, an understanding of the relative importance of development and research as they influence the economics of manufacturing.

Development of Production Welding Techniques

Production requirements in the automobile accessory field require special machines, automatic inspection and timing devices, personnel consideration and careful attention to specific applications

by J. Raymond Wirt

AT DELCO-REMY we make electrical components for passenger cars, trucks, busses, tractors and airplanes. The products are generators, cranking motors, voltage regulators, horns, switches, solenoids, ignition coils, distributors and storage batteries. Each of these assemblies consists of a number of parts welded, brazed, riveted, staked, soldered or bolted together.

The several products must be made of sufficient quality to render efficient service throughout their life, yet must be made efficiently and economically. Increases in labor, material and sales costs along with higher taxes must be met and counteracted by the increased efficiency of our equipment and operators, by the use of new materials, or by new or different production methods.

RESISTANCE-WELDING MACHINES FOR PRODUCTION WORK

One production process which has proved particularly helpful in keeping production costs down, as well as keeping quality consistent, is resistance welding. Several forms of operation are performed in resistance-welding machines other than straight spot or projection welding such as hot upsetting, braze welding, silver brazing, soft soldering and combinations of one or more of these which may be performed simultaneously.

Our products are relatively stable in design with few yearly model changes. Most design changes are made to improve quality performance or to secure greater production economy. Production is high and reasonably constant so that our tendency in all production methods is to install special machines with more original capital outlay than would be required by a standard machine, in order to secure the best production economy. It has been demonstrated that when the tooling is justifiably elaborate, as dictated by the production volume, better quality and consistency of product results.

Standard welding machines are often built into multiple operation machines as a production operation often with automatic control and no operator in constant attendance. Automatic inspection devices are sometimes incorporated in the machine which through mechanical or electrical methods indicate whether a weld has been made.

AUTOMATIC CONTROLS

One form of this automatic inspection device measures the thickness of the finished part and automatically ejects parts which are too thick indicating that insufficient heat or pressure has been used to make the joint. Another form is the use of a current-indicating relay in the secondary loop of the welder which is normally closed to an ejection device unless sufficient minimum current flows to open the relay and allow the parts to pass. Automatic rejection of parts which do not conform to the standard tests indicates immediately when trouble is encountered so that the location and correction of the trouble follows very closely its beginning to appear. The quality of the weld is determined by destructive testing at regular periods according to the production rates some being tested at 15 min. periods and others every half hour.

In 1940 we had approximately 40 resistance-welding machines several of which have been replaced. At present we have some 150 resistance welders of all types. This increase has been accomplished with constant design changes but no major change in the type of products.

We began originally with one 50-kva. machine available for laboratory development. At the present time we have one 20-kva. single-bench welder, one 20-kva. series, one 100-kva. press welder, and one 200-kva press welder which can be used to develop techniques, tooling and welder settings to be used in the production departments when the job is put on production.

J. Raymond Wirt is with the Delco-Remy Div., General Motors Corp., Anderson, Ind.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

OPERATIONS PRETESTED

Most of the welding engineers have through experience, training and custom developed preconceived ideas regarding the possibility or feasibility of accomplishing various joining operations which may or may not be logical, yet which can be erroneous if actual trials are not made with an open mind and sufficient tests to get a true picture of the facts. Welds which are both efficient and economical can successfully be made even through previous tests and printed information may indicate otherwise. The Engineer who uses all of the technical information, experience and techniques available to accomplish an operation will find to his surprise that often a job which looked impossible at first examination can turn out to be one which can be made into a relatively trouble-free production job. The important thing is to use all the tools available to assist in accomplishing a job rather than to build up reasons why it cannot be done.

The design and development work which may be done in the laboratory must be translated into production in order to realize any financial return. In order to successfully duplicate the laboratory results in addition to the design of the parts and welding fixtures it is necessary to know the limits on the welding procedure which will produce satisfactory production parts. Some of our jobs may require synchronous timing while the majority will require nonsynchronous timing. Some jobs will require low pressures with standard machines while others requiring low pressures will require fast follow.

Others may require higher pressures than the literature would lead us to believe is required.

It is always desirable to use a machine for the laboratory development which is similar to if not exactly like the machine to be used in production. Even then it is necessary at times to use certain instruments to check welding force (force gage) timing (cycle counter), wave shape (oscilloscope), voltage both primary and secondary as well as the physical dimensions of the parts to insure satisfactory production.

Most of the welding machines produced at present are built with good electrical and mechanical features which should give long and relatively trouble-free life.

PRODUCTION AIDS

Machines which may be perfect in mechanical and electrical characteristics are not complete unless considerable thought and planning have been used in securing ease of maintenance and the maximum in operator comfort. While these items may add slightly to the original cost of the machine the investment certainly pays dividends in increased production and decreased maintenance costs throughout the life of the machine. Considerable thought and design work has produced a dial-type welder such as shown in Fig. 1. Most of these machines are series type with 10 welding

Fig. 1 Shows a typical dial machine

stations but only 5 indexes per revolution. Two parts of the same kind can be loaded by an operator simultaneously. With adjustable index speeds and dial tables of large enough diameter to allow one, two or three operators sufficient room to work efficiently, production output can be changed to satisfy varying requirements. The dial table and mechanism is so arranged that the operators can face the table with sufficient knee room to sit comfortably and secure identical movements with both hands. This balanced movement secures maximum output with minimum operator fatigue. When series machines are used the duty cycle on the transformer is reduced to one-half that of a standard machine, the rubbing or contactor block between the knee and the dial table is eliminated and since the secondary loop is very small, the power factor is relatively high thus reducing the primary current.

In addition to the 10 station 5 index per revolution dial welding machines we have 10 station 10 index machines where more than one welding operation is performed simultaneously and we have some machines with two or three transformers and welding heads which perform welding operations without removing the parts from the fixture.

Welding machines of the type shown are dependable. We have one machine in a production line with no storage available on either side of the operation which

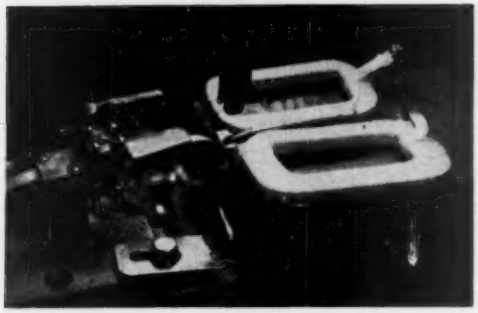


Fig. 2 Shows the joining of field coils in an air-operated press welder with automatic feeding of the silver-alloy ribbon

produces 7600 welds per hour, has 3 operators working and in 3 years we have lost the line flow twice, once for $1^1/_2$ hr. the other time for a half day. This machine runs 8 hr. or more per day 5 to 6 days per week. There are more than 130 operators doing operations subsequent to the welding operation who are dependent on this machine for their supply of parts. It can readily be seen that under these conditions it is necessary that this machine produce good parts all of the working day every day.

TIMING DEVICES

When we began our program in 1940 a high percentage of our welding machines had mechanical or magnetic contractors with either visual or cam-type timers which were driven from the machine mechanism. A study of maintenance cost on our plain magnetic contactors revealed that we were paying for tube-type contactors each year without having them. As a consequence a program of replacement with tube contactors was begun.

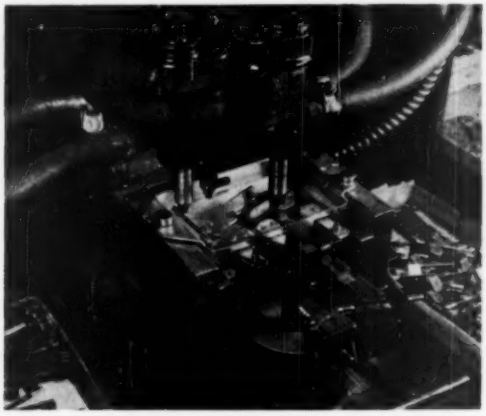


Fig. 3 Shows the welding of resistors to the regulator base

The right-hand electrode is used on each of the two series welds. Since the current path on one weld is twice as long as the other, a phase-shift heat control with automatic transfer relay gives 50% heat for one weld and 100% for the other. The position of the fixture with relation to a limit switch determines the setting used

The Inspection Department had found through years of poor welds that welds which were blue and burned had at least been heated to the welding temperature. When we began to replace the erratic type of timing with electronic sequence controls and began to efficiently water cool the welding electrodes, the better the quality of weld generally, the less it looked like a weld. It took quite a while for our people to realize that appearance in a resistance weld is a very poor measure of the quality of the joint.

As soon as a high percentage of the machines were equipped with proper timing and pressure equipment a system of set-up cards which gave all the data necessary to give consistent welds was begun. This job set-up card gave tap settings on the transformer, squeeze, weld hold and off time, pressure, electrode or fixture numbers and any other information which was necessary. Whenever unsatisfactory parts are being run the inspector checks the machine setting and the condition of the parts. If the settings are right, our process welding engineers are called to locate and correct the trouble. As the quality and consistency of our welding became better the old phobia against welding began to disappear until now we have only a few who have had very little contact with welding who are not enthusiastic about its uses and applications. New applications come not only from the product engineers but often from the production people themselves. Our personnel has risen from 1 in 1940 to 6 welding engineers now.

PERSONNEL

These welding engineers interest themselves in the various phases of welding although each is a specialist in one or more types of operation. Their training in the fundamentals of welder operation enables them to quickly determine what is causing trouble and secure the proper personnel to correct the trouble be it electrician, pipe fitter, tool maker or millwright if it be the machine, or tool correction or other remedies as needed

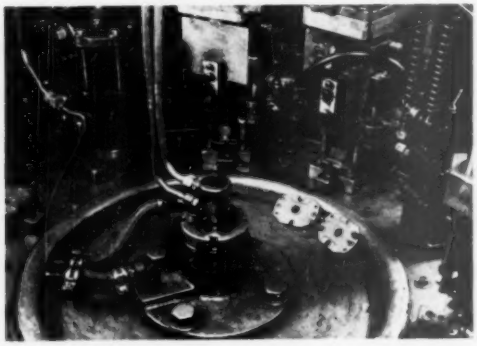


Fig. 4 Shows the hot upsetting of spring posts and studs into the distributor-weight base

These parts are case hardened all over. The operations shown are left, push plate down into position, then upset stud posts, next upset spring posts, then eject. The hopper feed for the spring posts is shown in the lower right hand corner

if the parts are not right or material analysis if the material is not right. By being specialists they are able to quickly determine what is to be done, and have it done, thus getting production going again as rapidly as possible. By their knowledge they are able to suggest preventive maintenance when it is needed and develop methods of changing troublesome parts. By a system of moving the most troublesome maintenance item into the "Public Enemy Number One" spot we are able to systematically eliminate troublesome equipment.

In ordinary times trouble shooting requires only a small part of the engineers time. Development of new techniques and proving new applications, testing new materials and securing data on costs of production for new methods are his main duties. We have found that using the engineer for trouble shooting has kept our downtime to a minimum with no special labor classifications in our maintenance department to service our welders.

APPLICATIONS

Some typical applications of welding cover:

1. Replacement of soldered joints.
2. Replacement of bolted or riveted joints.
3. Replacement of copper-brazed joints.
4. New designs primarily for welding.
5. Hot upsetting to replace cold riveting.

Replacement of Soldered Joints with Welds or Braze Welds

In the automotive industry the plated parts are largely zinc for under the hood or under dash components. With the advent of bright zinc plating the trouble we had been having with soft soldering was increased to such an extent that it was no longer economical to use soft solder on a large number of jobs. It was found that welding of copper wires to the zinc-plated steel was consistent and economical. The use of tungsten or molybdenum facing on the electrode gives sufficient heat to form brass which joins the wire firmly to the steel giving a joint which is stronger mechanically and better electrically than can be obtained by a simple soft-solder joint. The cost of the solder, flux and the longer time necessary to make a soldered joint serve to justify the purchase of resistance welding equipment.

Fig. 5 Shows the hot upsetting of bearings in the distributor breaker plate

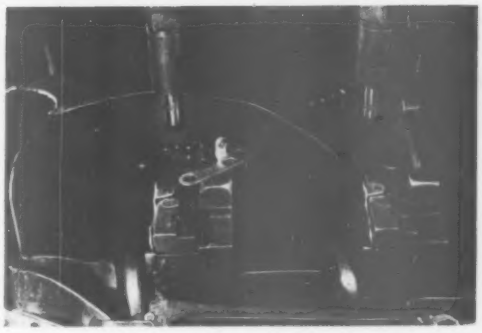


Fig. 6 Shows a shuttle fixture used in hot upsetting the contact rivet into the distributor-contact support

The time necessary to make a good soft soldered joint varies with the thickness of the parts, the cleanliness of the material, the type flux and solder used and the mood of the operator. Once a resistance welder is set up and operating satisfactorily the only variable in the production cycle is the time consumed by the operator in loading and unloading parts. A rhythm can be established by the operator which will insure the maximum production with minimum operator fatigue.

Replacement of Bolted or Riveted Joints

Bolts or rivets each require holes in the parts to be joined. These holes must be pierced in the punch-press operation or drilled subsequently. The cost of piercing the holes is low provided they can be secured during some other operation but drilled holes are fairly expensive. Bolts, nuts and lockwashers are expensive not only from their first cost but assembly costs are especially high. Rivets are relatively inexpensive generally but the labor required to assemble them is at least as costly as a resistance-welding operation. In either case the basic cost of the part is higher than could be secured by spot or projection welding. The saving on one part from which two bolts with nuts and lockwashers were removed paid for a dial welding machine with tools in about six months. It is almost impossible to make a waterproof joint using bolts or rivets without expensive gasketing and since the emphasis on all ordnance seems to be toward waterproofing the fact that no holes are pierced in the welded parts tends to simplify this problem.

Replacement of Copper-Brazed Joints

Maintenance on brazing furnaces is rather high and parts which are made from stampings, especially if a drawing operation is included, warp and deform due to the relief of cold-working stresses when the parts are annealed at the brazing temperature. This warping requires a straightening or seating operation after brazing. At times it is more economical to increase the gage thickness of the material in the parts to resist warping than it is to restrike the parts after brazing. This increased material thickness is not necessary with parts which are welded since the annealing is not present in areas which are critical as to dimensions. A considerable saving in maintenance and power costs is affected by the change from brazing to welding and more tolerance is allowable on dimensions since press fits are no longer necessary.

New Design Primarily for Welding

When a new product or major revision of one of our present products is being considered, rivets, bolts, nut clearances and close tolerances can be minimized with the accent on function and ability to weld and handle the parts. One product which was recently redesigned had 25 to 35 parts eliminated by the use of welding. An outlay of several thousand dollars was repaid by the saving effected in less than 6 months. Four and a half years of designing, redesigning and testing elapsed between the original sample and the changeover on production. This product is typical of others on which welding has been properly and successfully applied.

Hot Upsetting to Replace Cold Riveting

Ordinary riveting, staking or spinning is much more economical when the rivets or studs are soft, but when good electrical contact must be secured or when the exposed end of a stud must be hard, it is often more economical to hot upset. Whenever a part is cold riveted, spun or upset, it is necessary to stress at least a portion of the material beyond its elastic limit. The portion which is so stressed will vary with the design of the parts, the design of the tools and the composition and condition of the material. The portion of the riveted material which is not stressed beyond its elastic limit provides a certain amount of resilience or spring back which causes the tightness of the joint to vary.

When parts are hot upset the pressures used are considerably lower than those for cold upsetting or riveting; the heat allows the metal to be upset in the plastic range and when the upset metal is cooled from the electrode and is perfectly solid the shrinkage obtained by further cooling will tend to increase the tightness of the joint. It is as economical of labor to hot upset hardened parts as those which are soft. Several of our applications have been justified by saving in differential hardening costs.

Case-hardened parts which required a wear surface yet required a soft end for riveting or staking were copper plated on the portion of the part which was to remain soft then carburized and hardened. Under ordinary conditions the copper plating will protect the covered surface from carburization but at times the parts were hardened all over. When this condition occurred, it was impossible to secure good cold upsetting, since the parts were brittle and would either split or not head over properly. The elimination of the copper plating with its attendant hand loading of plating racks paid for the welding machine in a relatively short time while the quality of the finished parts is better and more consistent.

One example of a development project is the work done on joining copper straps for cranking motor-field coils. These coils were originally soft soldered using a U-shaped bend in one piece to enclose the straight end of the other.

We first tried a lap spot weld but the quality of the welds was not consistent. We then tried the introduction of iron powder to generate heat at the junction. The iron powder did secure sufficient heat to insure welds but the application was slow, the amount was difficult to control and the heat application was critical. The next step was to try dip tinning the ends with soft solder but it was found that the thickness of the solder coating was very critical if welds were to be secured and the production tinning would be expensive. It was found that the welds made were copper to copper. The soft solder seemed to alloy with the copper or volatilize during the heating period. We then tried the introduction of brazing alloy between the parts using first a 50% silver alloy but its burn-off characteristics and welding quality were not acceptable. A 15% silver-alloy ribbon 0.003-in thick was then tried and the results were acceptable. Molybdenum-faced electrodes were used; the ribbon was fed out automatically on the upstroke. The ribbon burns off at the edge of the joint and examination of the joint reveals that there is 0.0001 in. or less of alloy remaining between the copper straps. The heat time is approximately 8 cycles and 2 operators now produce as many parts as 4 operators would produce using 2 automatic soldering machines. In addition several thousand pounds of tin lead solder, flux and $^3/_4$ in. of copper strap per piece are saved.

During the investigation for this job we found that while copper will weld to steel, it will weld much better if the steel is zinc plated. This development opened the field to a number of applications which were then followed through. As each new application of welding to another product was made some modifications of the technique were made which opened up more applications and as these applications were put into production more appeared to be feasible. In each case where a soft-soldered joint was replaced the production rate went up, the joint was better both electrically and mechanically, the appearance was better and there was no cleaning problem afterward.

Electric Utility Welding in the Shop and Field

Most of the welding processes are utilized in maintenance and overhaul operations of a municipally-owned system of furnishing electric power

by David P. O'Connor

THE Department of Water and Power of the City of Los Angeles operates a municipally-owned system for furnishing electrical energy within the city and is interconnected with private systems and municipal systems of adjoining municipalities.

Power is obtained from a number of hydroelectric plants along the Owens River Aqueduct, which extends approximately 300 miles to the north of Los Angeles; the Hoover Power Plant on the Colorado River, 300 miles east of Los Angeles, and three local steam-electric plants. The total generating capacity of these plants is approximately 1,114,000 kw.

The General Plant Division of the Department, with its electrical and mechanical shops performs the major overhaul and maintenance work on the generating equipment of these power plants and distributing stations. The Welding Shop has an important part in this work.

The welding on the generating equipment is usually progressed along with the general overhaul in either the field or the shop, depending on the condition. The various welding processes used are oxyacetylene, electric, inert arc and metal spray.

Both impulse- and reaction-type water wheels are installed in the hydroelectric generating plants. On the impulse-type water wheels a careful inspection is made of the cast-steel buckets to determine the extent of the cavitated areas and cracks. After marking these areas, the damaged portions are chipped or ground to remove porosity, cavitation or cracks in preparation for welding. The welding is done in the following manner: Using a 19–9 stainless electrode type 308 or 347, the cavitated areas are built up, and as each electrode is deposited, the welded area is immediately peened with a pneumatic hammer to relieve stresses and insure against cracks in the future. These buckets, though they are cast steel, ordinarily cannot be preheated as most of them are balanced with lead weights. When cracks have occurred in the buckets, due to water hammer and fatigue, these cracks are chipped and welded from the base of the crack to the outer edge of the bucket, peening each deposited rod as the weld progresses. An excess of metal is deposited, peened, then ground to the original contour of the buckets. This method has proved successful on cracks up to 6 in. in length on buckets of 18 to 24 in. in diameter where the nozzle pressure exceeds 400 psi.

Fig. 1 Needle valves after stainless overlay and machining have been completed

The repairs to the nozzles and the throat rings are made in the shops. Originally most of the nozzles and seats were of cast bronze, and, due to excessive cavitation, did not lend themselves readily to welding. The casting had to be preheated and the affected areas welded or brazed with an oxyacetylene torch to avoid porosity in the weld. This was an extremely difficult job due to the shape of the needles and throat rings. These castings instead of being welded or brazed were usually turned on a lathe, polished and restored to service. In the past ten years, cast-steel nozzles and

David P. O'Connor is Welding Foreman, General Plant Division, Dept. of Water and Power, City of Los Angeles, Calif.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

throat rings with stainless-steel overlay have replaced most of the bronze type. These steel castings are turned to a size $^1/_8$ in. smaller or larger than the finished size, as the case may be. A 19–9 stainless overlay is then deposited on the casting, after which they are turned to their original size and shape and polished (Fig. 1). These nozzles are welded on a turntable so geared that the welder sits in one position and applies the electrodes as the nozzle rotates. The nozzle is set in a vertical position and the welding is done in a horizontal position. After machining nozzles with surface areas in excess of 4 sq. ft., not a pinhole or flaw is to be found on the entire nozzle. This is the proof of exceedingly good welding done in a workmanlike manner. The value of the stainless-steel overlay on the steel castings, in preference to bronze castings, can be seen by steel nozzles that have been in constant operation for over seven years, and no appreciable wear or leaks have occurred on either the nozzle or throat-ring seat. Prior to this stainless-steel application, the bronze nozzles had to be removed and machined at least once a year on some units.

With respect to the reaction-turbine installations, the resurfacing by stainless overlay of cavitated areas on the large 115,000-hp. turbine runners at Hoover Power Plant is by far the major problem, due, not only to the volume of the work to be done, but the time allowed to complete the work. The cavitated areas are checked over and outlined in chalk in preparation for removal of the faulty metal by chipping or grinding (Fig. 2). The outline of the chipped area is chipped a little deeper with a round nose chisel so as to assure a good shoulder of stainless steel and prevent future undercutting. The area surrounding the fault is ground clean of rust to prevent porosity at the edge of the weld. It has been found that a surrounding bead of mild steel deposited as flat as possible with an E6012 electrode helps toward a better stainless-steel bond. The castings are of a 30 to 35 point carbon, and difficulty has been encountered where the 19–9 met the castings at the end of the deposited overlay. If the chipped area is over $^3/_{16}$ of an inch in depth, it is built up with an E6012 electrode to within $^1/_8$ in. of the finished surface, and the 19–9 overlay is then deposited after which the welded area is then ground to the original contour of the casting (Fig. 3). Ninety per cent of the welding is done in either horizontal, vertical or overhead positions and requires the welders to work in cramped and awkward positions. Approximately ten per cent of this type of work can be accomplished in the down-hand or flat position. Dilution of the deposited stainless is not a problem, as cavitation and not corrosion is the main offender. Runners have been welded with mild steel as well as stainless, and results have been carefully checked over a period of twelve years. At present, the Department and the United States Bureau of Reclamation engineers agree that the stainless overlay is worth the cost of application. The mild-steel overlay will outwear the original casting, but will cavitate, whereas the stainless overlay shows no apparent wear over a period of eight to twelve years of constant use. Spare runners are plotted in accordance with experience gained in the past for expected cavitated areas and are

Fig. 2 Close-up showing the outlined area and a portion of the chipped and welded surface prior to grinding

Fig. 3 The bright sections of the blades are the stainless overlay

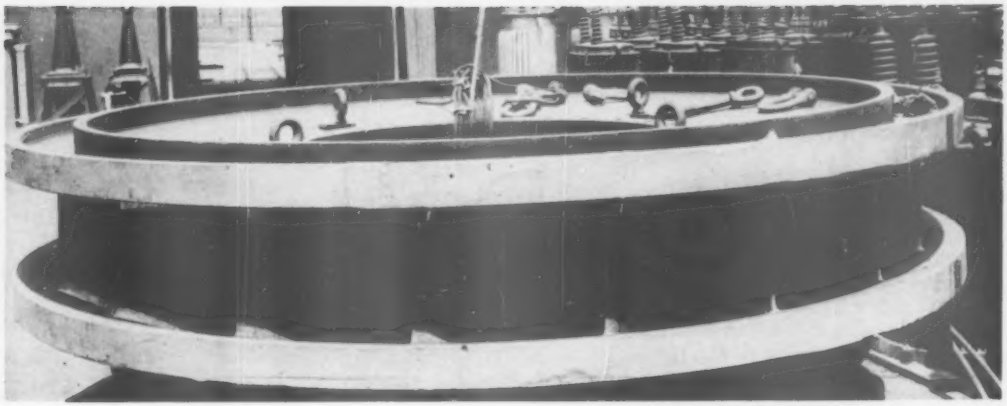


Fig. 4 Spare runner for Hoover power plant, 115,000 hp. unit

chipped and overlayed prior to installation. This work is done in the shop where the runner can be turned to make welding positions more favorable (Fig. 4). These runners weigh 35 tons, are 13½ ft. in diameter and have a vane height of 19 in. Four to six welders work on the runner at one time.

The wicket gates that operate in conjunction with these runners are welded in the shop. A set of these gates consists of twenty-four castings weighing 1500 lb. apiece. The lower end and 19 in. of the upper end of the gate shafts are turned down in a lathe ⅛ in. on a side; the heel and toe seats of the blades are machined down prior to welding. The shafts of the gates are welded in a vertical position on turntables (Fig. 5). By standing the gate stems in a vertical position, the weld metal is deposited faster and the distortion is held at a minimum. The turntables are driven by a variable speed-reduction gear box motor with belt drives that allows two gates to turn in the same direction for ease of welding. On an 8-in. diameter shaft over 5 ft. long, the shafts are seldom out more than ten to fifteen thousandths (Fig. 6). The realignment of the shafts is done after they are rough turned and still have fifteen

Fig. 5 Welding the wicket gates in a vertical position on the turntable

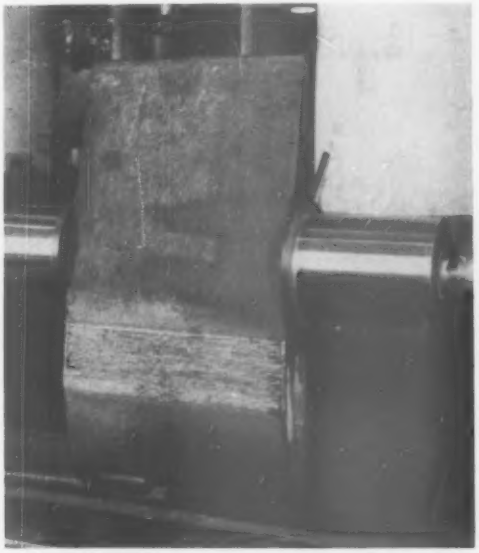


Fig. 6 Finishing the stems on the wicket gates. (The heel and toe are yet to be machined.)

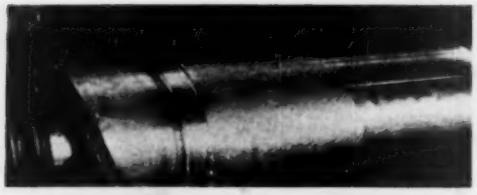


Fig. 7 Magnaflux of crack spare-wicket gate stem

to twenty-five thousandths excess metal on a side. This straightening is done by spot heating with an oxyacetylene torch, and corrections are made so the finished shafts are no more than three thousandths out. Cracks have been found to exist in the gate stems and the defective area was shipped and ground to the base of the crack and then magnafluxed (Fig. 7). As each electrode is deposited, the weld is peened while hot. With cracks 4 in. long and over $^3/_4$ in. deep after the weld has been completed, distortion has been held to less than five thousandths.

On small horizontal units where the turbine shafts have been worn by oil rings or packing glands requiring resizing of the shaft, the unit is set up between self-aligning bearings. An induction heating coil is wrapped around the shaft, and the shaft is rotated while being welded (Fig. 8). The weld is put on in a continuous bead in a downhand position. After welding, the shaft is cooled slowly, and during the cooling process is continually rotated. Careful checks show that there has never been over $1^1/_2$ thousandths distortion in a shaft repaired in this manner.

Repairs to penstocks, energy absorbers (Fig. 9), and draft tubes are also done during overhaul periods unless they happen to be emergency jobs. If an excessive amount of cavitation has occurred in a draft tube, replacement of sections is sometimes the most economical type of repair. These sections are layed out, cut and formed in the shop. Due to the close quarters in which the draft tube sections have to be fitted and welded in place, it is necessary to make these sectional parts of several pieces for easier installation in the field. The areas where the worst cavitation has occurred have been repaired with a stainless-sheet liner welded over the area for added protection.

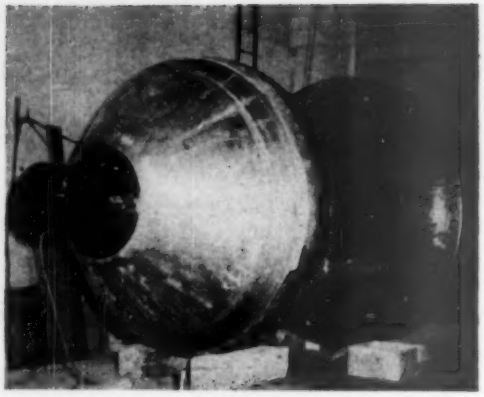


Fig. 9 Energy absorber for Hoover Power Plant Unit. Bright surface is 18–8 stainless clad plug welded to casting

The Department at present operates two steam plants: one at Seal Beach, Calif., consisting of two units, 75,000 kw. total capacity; the other at Los Angeles Harbor has five units, 363,000 kw. total capacity. The welding done in these plants on the turbines, condensers, pressure vessels and high-pressure piping is done by Certified welders of the General Plant Division.

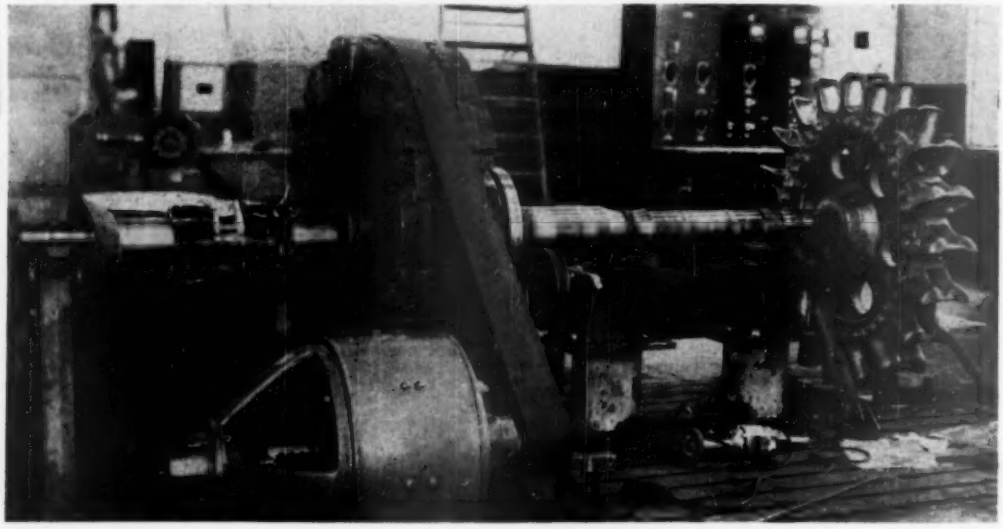


Fig. 8 Induction coil on left side of 800 kva. unit; right side has been welded and is ready for machining

Fig. 10 Chipped and welded area on lower half of 65,000-kva. steam turbine

These welders are certified under the A.S.M.E. Boiler Code Class U68 as the temperatures involved are over 900° and the pressures at times exceed 1800 lb. to the square inch. Unless piping changes are being made or leaks occur in the system, the larger jobs are done during the overhaul of the units.

When the steam turbines are dismantled, the upper and lower halves of the high-pressure cases are carefully checked and magnafluxed. If cracks are found that are too large to be ground out, they are chipped and ground, then again magnafluxed in preparation for welding. These castings are of carbon or chrome molybdenum steel and of quite intricate pattern, and they weigh from 15 to 90 tons. The area surrounding the cracks is packed with asbestos blankets (Fig. 10), and several natural gas torches are used to preheat a section of the casting to 375° F. The rise in temperature is held to a maximum of 50°F per hour, and during welding the temperature is not allowed to vary by more than 25°F. The temperature recordings are usually taken with Tempil sticks; however, potentiometers also have been used. The weld progresses with the welder welding the cross-section area of the weld. To explain—in a vertical weld, the entire cross-section area would be built up from the lower end of the weld to the top As each electrode is deposited, the weld is immediately peened while in a very hot state. After the weld is completed, the casting is cooled to approximately room temperature at a rate of 25° per hour. The completed weld is ground smooth and again magnafluxed.

The cracks that have been welded in the aforementioned manner have not reappeared and show no signs of recurring after several years' service.

Boiler tubes have been seal welded to the drum on recommendation of the manufacturer. Each tube was fitted with a transite plug to prevent shot, weld splatter and flux from entering the tube. The tubes were shot blasted before welding and again after welding to remove all flux from the weld. Each tube was seal welded to the drum with a single bead weld. In this particular drum the tubes ended about 1 in. from the inner surface of the drum. The drum wall thickness was 4 in. After welding and shot blasting, the tubes were rerolled and the drum hydrostatically tested.

In welding of main steam pipes, including carbon molybdenum and chrome molybdenum steels, the Department employs the use of induction heat for preheating and stress relieving all welds.

In the past, it has been necessary to make welds on the main stop-gate valves of some of the boilers where distortion or warpage would mean the loss of the service of 65,000 kw. capacity. These have been repaired by wrapping the valve with induction coils, and when the temperature has risen the required amount, two welders work on the valve simultaneously, one on each side; this speeds up the operation and prevents distortion, so that the valves seat properly after welding. During cooling the valve is turned every half hour to offset sagging.

The repairs required on the turbine spindles and blading are varied as to the make and type of the unit. Stelite strips are silver-soldered on the leading edge of the blades whose peripheral speed is approximately eleven miles per minute. Shrouds and blade ties are

Fig. 11 Stainless-steel studs in cast-iron circulating pump and lower stainless-steel plate

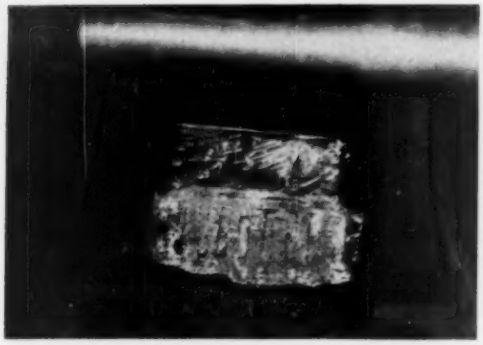


Fig. 12 Completed discharge throat on circulating pump after welding and grinding

welded to the blades; this is a very delicate job as no arcing marks, pits or under cuts are permitted. Tie wires, running through a group of some types of blades, are resilver-soldered. Eroded sections of the shaft seals have been built up and remachined. The success of aforementioned jobs depends on the ability of the welder to handle many different types of materials under different circumstances

The cast-iron case of a horizontal circulating water pump, whose capacity is 3,500 gpm., was badly cut through a fin inside of the case. The area was chipped until enough width was obtained to install stainless-steel studs for supports (Fig. 11). Pieces of ten gage stainless steel were fitted above and below the studs to

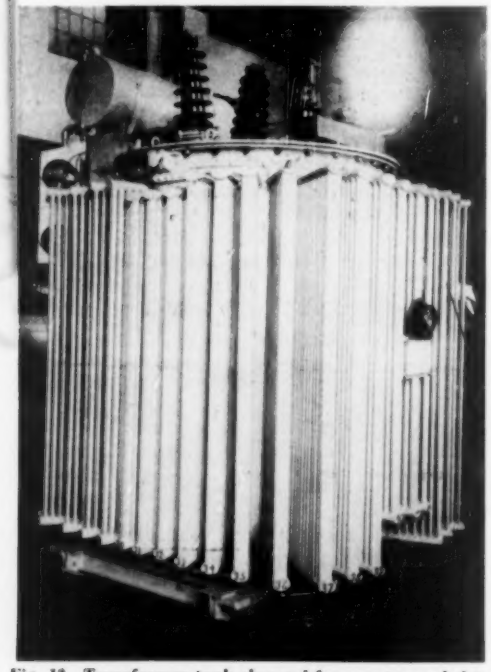


Fig. 13 Transformer tank changed from water cooled to self cooled shop-fabricated radiators

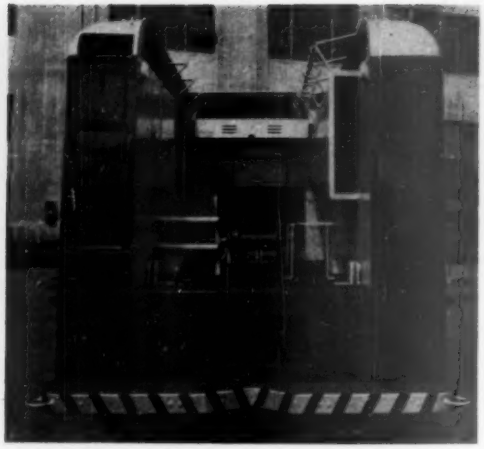


Fig. 14 Overhead line truck. Shop-fabricated body

bring the fin out to the desired length. The lower plate was welded directly to the studs. Holes were drilled in the top plate that would permit the top plate to be welded to the same studs after both plates had been welded in position to the studs. The exposed ends of the plate were welded together. The entire stainless-steel inlay was then seal welded to the cast-iron case (Fig. 12), and has been in operation for three years and shows no sign of cracks where the stainless steel was bonded to the cast iron.

During the period of time between these major overhaul jobs in the field, and the aforementioned wicket gates, needle valves and throat rings, work continues in the shop on the repairs to tools and equipment such as drag line, clam shell rigs, bull dozer and posthold augers and auger cutters, all of which receive the necessary building up and hard facing. The auger cutters are plow-steel stock, flame cut to shape and hard faced with 30–40 acetylene tube borium. The augers are protected on their leading edge with tube borium (30–40) and on the balance of the flight edge with a high chrome,

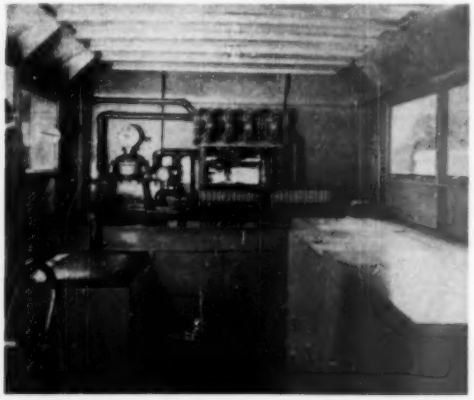


Fig. 15 Shop-fabricated body and installation of transformer oil filter unit

high-carbon electrode. These augers are used to drill holes up to 38 in. in diameter, ranging in depth from 9 to 14½ ft. On transformers requiring the changing from water cooled to self cooled, the welding shop fabricates and installs the necessary radiators to make the change (Fig. 13). Transformer tanks and lids are constantly being repaired for leaks and broken hanger lugs. Special truck bodies designed for Department use are welded in the shop (Figs. 14 and 15). Sheet-metal pull boxes, cabinets and switchboard frames are also welded.

The ever-growing need for electric power in Los Angeles has caused the municipally-owned Department to expand continually, and always be on the alert to find new ways and means to bring cheaper power to the consumer. Engineers have designed underground transmission lines that operate at 132,000 v. Welding enters the picture here as these lines have to be filled with either gas or oil to keep out moisture. The brass sylphon tanks and reservoirs, used to transport the vacuum treated oil from the oil house to the manhole locations and to permit the oil in the oil-filled cables to expand when the cable is carrying a heavy load, are fabricated in the shops. The cast bronze heads and flanged rings on these reservoirs are brazed to cylindrical tubes. On the overhead transmission lines, voltages as high as 287.5 kv. are carried. These lines are now being worked while hot or live. Now lightweight tools of aluminum and its alloys have been designed and fabricated. These are welded by the inert-arc process. As the city enlarges, the requirements of the Department grow, and the use of all types of welding continually plays an important part in the maintenance work of this large publicly-owned electric utility.

Welding in Engineering Education

Discussion by F. Koenigsberger

I have read with great interest the paper by R. S. Green on "Welding in Engineering Education" in the April 1950 issue of THE WELDING JOURNAL, and I should like to make the following contribution to the discussion on the subject.

The definition and the "status" of the welding engineer, the need for specialized welding engineers in industry and the introduction of welding as an essential part of the general engineering courses at Universities and Colleges are matters which have been under discussion for some considerable time. It seems, however, that in many instances overenthusiasm has lead people to believe that welding engineering is an end in itself and not, as it really is, a means to an end. Welding is just one of many methods of production, and as such ought to be used where it is most suitable and efficient, i.e., when it helps toward producing technically and economically competitive articles.

It was, therefore, very satisfying to read that Mr. Green agrees with the opinion which the writer of this contribution has put forward on several occasions, that a welding engineer ought to have sound general engineering knowledge before he embarks on the specialized field of welding and the various special subjects connected with it, such as the determination and critical evaluation of welding procedures, which welding process is best used in a particular case, the design of welded structures, the running and maintenance of welding plant, etc.

F. Koenigsberger, Lecturer in charge of Welding Engineering in the Mechanical Engineering Department, College of Technology, Manchester University.

Almost as often as we find people who are prejudiced against welding (considering it to be a patching-up process only useful for repair work) we meet people who slow up its development and use by failing to see its limitations. Only sound general engineering knowledge will enable welding engineers to discriminate each particular problem and to hold their own with other engineers.

It is very interesting to note that in the U.S.A. the need for highly qualified welding engineers of the above standard is large enough to justify the institution of a University Course with a final degree in "Welding Engineering."

Our experience in Britain is indicated by the following example: A specialized course which leads to a "Higher National Certificate" in Welding Engineering was introduced in the Manchester College of Technology in 1944. The writer found that after an initial rush of students lasting about three years, interest in the Course declined, and this tendency appears to have been experienced in many Technical Colleges in the country. This is probably due to the fact that the number of positions in industry for highly specialized welding engineers is limited and the immediate demand was satisfied. Furthermore, the remuneration attached to such positions is apparently less attractive than that for general mechanical engineers.

In the general engineering courses at Universities and Technical Colleges, it is therefore all the more necessary to give welding its rightful place as a production method which has not only proved its usefulness, but has established itself in many industries as a means of production of value at least equal to that of other methods of manufacture. Not only should it be included in courses of general workshop technology where its features and its special problems have to be taught and discussed, but also in the design courses for struc-

(*Continued on page 764*)

Crack Sensitivity of Aircraft Steels

An investigation of the relative cold-crack sensitivity of several kinds of weld-filler metal such as are used in aircraft construction

by A. W. Steinberger, B. J. DeSimone and J. Stoop

SUMMARY

THIS paper describes an investigation of the relative cold-crack sensitivity of several kinds of weld-filler metal such as are used in aircraft construction. The principal materials that were studied were modified S.A.E. 4320, 4330 and 6130. Tests were also conducted with S.A.E. 4130, N.E. 8630 and types 310, 347 and 410 stainless-steel filler materials.

Type 410 stainless was found to have the highest crack sensitivity of all types tested.

Modified S.A.E. 4330 had the second highest crack sensitivity.

Modified S.A.E. 4320 had an appreciably lower crack sensitivity than type 4330.

The S.A.E. 6130 had the lowest crack sensitivity of the principal materials studied with S.A.E. 4130 and N.E. 8630 being on approximately the same level.

With but two exceptions, all of the specimens welded with the atomic hydrogen process, and air cooled in the standardized manner developed cracks of varying magnitude, regardless of which of the filler rods was used. The two exceptions to this were the types 310 and 347 stainless filler rods.

No cold cracks occurred with any of the filler materials, regardless of the welding process employed when cooling was arrested at a suitable temperature and the part held at that temperature for at least an hour.

For the modified S.A.E. 4330, 4320, 6130, 4130 and N.E. 8630 filler rods, 400° F. was found to be the postheat temperature at which cracking would no longer occur upon subsequent cooling. 600° F. is recommended as a safe processing temperature to allow for the inevitable variation in materials and temperatures. This applies to parts up to $^1/_2$ in. in thickness.

The type 410 stainless material required a postheat temperature of 600° F. to prevent cracking. This value was found to be critical as cracking occurred at both higher and lower temperatures.

For those weldments containing dissolved hydrogen, a minimum time of 20 min. at the specified temperature was found necessary to prevent cold cracks in modified S.A.E. 4330, 4320 and 6130 filler materials. For parts of up to $^1/_2$ in. in thickness, 1 hr. proved to be a satisfactory period to allow for uncontrolled variables. In some instances, sufficient hydrogen remained after this treatment to cause cold cracks if the part was water quenched from the postheat temperature. A longer postheat time may permit water cooling if it is necessary.

When low-hydrogen welding processes were employed, no cold cracks occurred with even the most crack sensitive of these filler metals (type 410 stainless and modified S.A.E. 4330). This applied to cooling rates as great as those obtained by quenching the specimen in iced brine immediately after welding.

The foregoing substantiates the observations of other investigators [2,3,4,5] that in the absence of dissolved hydrogen or severe stress concentrations, cold cracking will not occur even under drastic quenching conditions.

Hardness was not found to be a controlling factor in determining crack sensitivity.

Argon arc welded and quenched specimens having a hardness ranging from 47 to 52 Rockwell "C" did not crack.

Atomic hydrogen welded and air-cooled specimens having a hardness ranging from 25 to 39.5 Rockwell "C" contained scores of cracks.

The optimum postheat temperature and time appeared to be approximately the same with all of the steels tested with the exception of type 410 stainless. The degree of cracking which occurred below the optimum values varied with the different materials.

Cracking occurs if the weldment is allowed to cool below the critical cracking temperature for even a few minutes prior to postheating.

Cracking was observed to progress for some time after the weldment has cooled where postheating was not used.

When stored at 40° F., cracking was essentially complete at the end of 24 hr. When stored at room temperature, cracking continued for a considerable period of time. All specimens that were stress relieved after cooling to room temperature developed cracks unless they were welded with low-hydrogen processes. The number and size of these cracks increased as the interval between cooling to room temperature and placement in the stress-relief furnace was lengthened.

Specimens containing cracks were examined prior to stress relief, and usually were more extensively cracked following stress relief.

Cold-crack sensitivity of hardenable steels appears to be directly influenced by the effective carbon content of the material.

The effective carbon content and the subsequent crack sensitivity may be reduced by any factors (such as alloying constituents and thermal cycles) which will tie up part of the carbon in the form of carbides.[1] The presence of carbides which are slow to dissolve during the very rapid thermal cycles involved in welding will reduce the crack sensitivity without necessarily reducing the ultimate physical properties of the steel after heat treatment.

INTRODUCTION

Welded parts of hardenable low-alloy steels are frequently employed in aircraft construction for both primary structures and nonstructural applications. These components are subjected to high multiaxial loading and severe vibratory stresses. In consideration of the stringent service conditions to which such weldments are subjected, it is essential that they be free of defects to a far higher degree than is necessary for most welded fabrications.

Cold cracks in the weld bead or adjacent

A. W. Steinberger, B. J. DeSimone and J. Stoop are with the Propeller Division, Curtiss-Wright Corp., Caldwell, N. J.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

parent metal are one of the major forms of weld defect encountered with the types of steel involved in aircraft construction. It is evident, therefore, that a better understanding of the factors influencing cold-crack sensitivity is of the utmost importance.

Numerous investigators,[2-5,7] have presented data showing that cold cracking is primarily due to the high aerostatic pressures produced when dissolved hydrogen is rejected during cooling and transformation of the steel.

The effects of thermal treatment, filler rod and base-metal composition and other factors have also been described.[1,7]

In many cases, these investigators were concerned with underbead cracks rather than cracks in the weld deposit. This was in a large measure due to the common use of electrodes depositing metal of low hardenability. The basic causes of cracks in both cases, however, appear to be the same.

The hydrogen theory has been so well covered by others,[1,2,4] that it will not be outlined in detail in this paper. It is sufficient to state that weldments made with materials of the types investigated may be made insensitive to cold cracking by:

1. Employing welding processes which will not introduce appreciable amounts of hydrogen into the weld-deposit or heat-affected zone.
2. Employing thermal cycles which will permit complete transformation of the austenite at some elevated temperature.
3. Employing filler rods and parent metal of such composition that transformation will be promoted at a temperature sufficiently elevated that the dissolved hydrogen can escape without building up high aerostatic pressures.

The work described in the following was undertaken for the purpose of establishing the relative influence of the various factors involved in the formation of cold cracks and to establish optimum values for the specific types of steel and filler rod employed in the fabrication of aircraft propellers. The information presented in this paper applies primarily to the materials described.

The hollow steel propeller blades under consideration are, or were, made of modified type 4320 or 4330 steel plates having the nominal compositions shown in Table 1.

The progress of the investigation was primarily directed toward the determination of the proper thermal cycles, filler-rod analyses and welding processes for obtaining the greatest freedom from cold cracks when welding these materials.

The three principal filler materials investigated were modified types 4330, 4320 and 6130 having the specified chemical compositions shown in Table 2.

A less complete study was also conducted upon filler rods made of S.A.E. 4130 and N.E. 8630 low-alloy steels and types 310, 347 and 410 stainless steels.

In conducting this project, several variables were investigated:

1. Crack sensitivity vs. arrested cooling and postheat temperature.
2. Crack sensitivity vs. filler rod composition.
3. Crack sensitivity vs. postheat time.

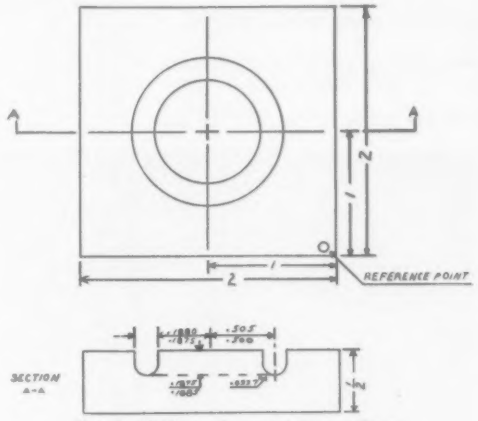


Fig. 1 Weld crack-sensitivity specimen

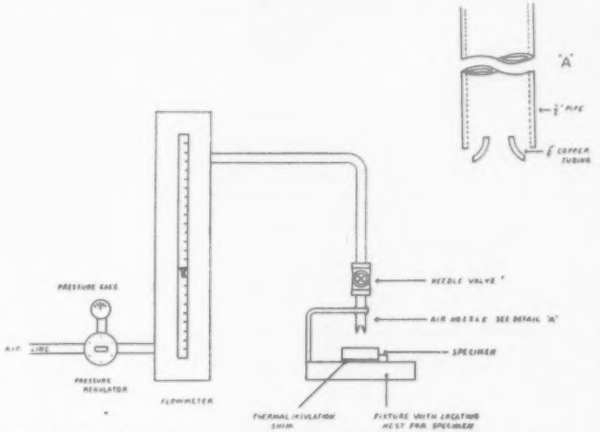


Fig. 2 Standardized cooling fixture for crack-sensitivity specimens

Table 1.—Specified Analysis of Plate Steel for Hollow-Steel Aircraft Propeller Blades.

Type	*C*	*Mn*	*Si*	*S*	*P*	*Ni*	*Cr*	*Mo*	*V*
4330 Modified	0.27–0.33	0.60–0.80	0.20–0.35	0.015 Max.	0.025 Max.	1.65–2.00	0.60–0.80	0.27–0.37	..
4320 Modified	0.17–0.22	0.60–0.80	0.25–0.40	0.015 Max.	0.020 Max.	1.85–2.20	0.80–1.00	0.35–0.47	..

Table 2—Specified Analysis of Filler- Rod Material for Hollow-Steel Aircraft Propeller Welds

Type	*C*	*Mn*	*Si*	*S*	*P*	*Ni*	*Cr*	*Mo*	*V*
4330 Modified	0.27–0.35	0.60–0.80	0.20–0.35	0.015 Max.	0.020 Max.	1.65–2.00	0.60–0.80	0.27–0.37	.....
4320 Modified	0.15–0.20	0.55–0.75	0.25–0.40	0.015 Max.	0.020 Max.	1.85–2.20	0.80–1.00	0.35–0.45	.....
6130 Modified	0.27–0.32	0.70–0.90	0.25–0.45	0.015 Max.	0.018 Max.	.....	0.85–1.05	.....	0.20–0.25

4. Crack sensitivity vs. dissolved hydrogen as influenced by the welding process.
5. Crack sensitivity vs. hardness of the weld deposit.
6. Crack sensitivity vs. rate of cooling to the postheat temperature.
7. Crack sensitivity vs. time at room temperature prior to stress relief with no arrested cooling and postheating.
8. Crack growth due to stress relief.

PROCEDURE USED IN CONDUCTING THE TESTS

During the initial phases of this investigation, actual hollow steel propeller blades or sections thereof were employed as specimens. The amount of scatter in the test results due to uncontrolled variables, and the difficulty of obtaining detailed information from production parts, made it impossible to make conclusive determinations. It was evident that a standardized form of specimen and testing procedure was needed in order to obtain reproducible results.

A review of the literature led to the adaptation of the circular-groove weld-bead specimen used by the Arcos Corp., Battelle Memorial Institute and others. This form of specimen is illustrated in Fig. 1. It has given very satisfactory and reproducible results when employed in conjunction with a standardized welding and testing procedure.

The following describes the general procedure employed in conducting this investigation. Deviations were required in certain instances for the study of specific factors.

Specimens were welded without the use of preheat.

All weld deposits were made upon type 4320 plate material.

The atomic hydrogen welding process was employed where not otherwise indicated.

After welding was completed, the

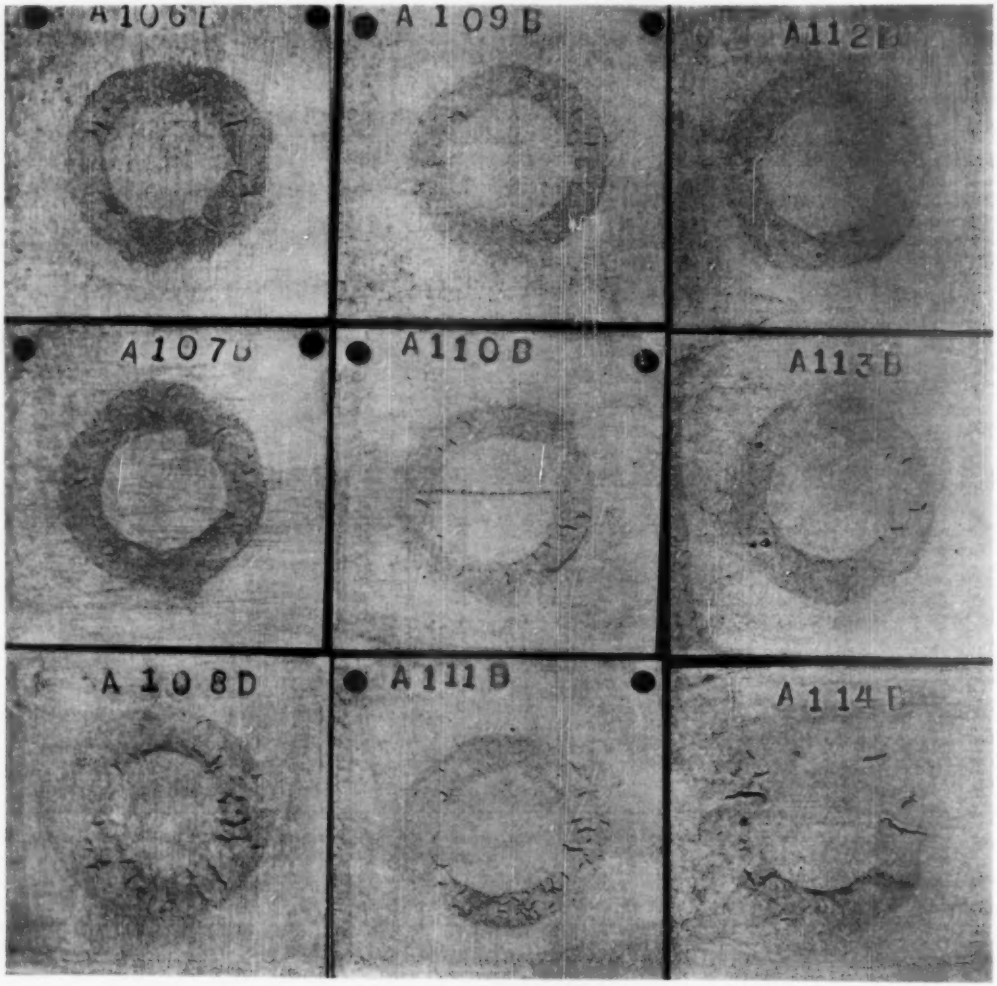


Fig. 3 Atomic hydrogen-welded specimens after arrested cooling and postheating for 1 hr. at 160° F.

(Top) Type 4320 filler material; (center) type 6130 filler material; (lower) type 4330 filler material

Fig. 4 Atomic hydrogen welded specimens after arrested cooling and postheating for 1 hr. at 200° F.

(Top) Type 4320 filler material; (center) type 6130 filler material; (lower) type 4330 filler material

Fig. 5 Atomic hydrogen-welded specimens after arrested cooling and postheating for 1 hr. at 250° F.

(Top) Type 4320 filler material; (center) type 6130 filler material; (lower) type 4330 filler material

specimens were immediately placed in a cooling jig, except when other than standard cooling rates were being studied. This cooling apparatus is illustrated in Fig. 2 and consisted of a locating nest positioned under an air nozzle having a fixed size and distance above the specimen. The nozzle contained a diffuser cone for the purpose of obtaining a uniform distribution of air over the specimen.

The air pressure and flow rate were standardized at 25 psi. and 600 cfh., respectively. These values were selected to approximate the cooling rate as measured on welds in a representative section of an actual propeller blade. Care was taken to insure that there was no excessive moisture in the cooling air.

Specimens which were not to be postheated were air-blast cooled to 200° F. and then water cooled to room temperature except where otherwise indicated. Water cooling from 200° F. saved a considerable amount of time and was not found to affect the final results.

Specimens to be postheated were cooled with the standardized air blast to the desired postheat temperature and then immediately placed in an induction-heated oven which permitted accurate automatic temperature control and rapid thermal recovery. With the exception of some of the earlier tests, and where otherwise specified, the standardized air blast was also employed for cooling the specimens to 200° F. after postheating. The specimens were then water cooled to room temperature. No difference was observed between specimens so cooled and those cooled to room temperature entirely with air.

Upon reaching room temperature, the specimens were placed in a refrigerator at 40° F. for 24 hr., to permit completion of cracking. After removal from the refrigerator, the specimens were stress relieved for 1 hr. at 1060° F. They were then surface ground under coolant to a depth of 0.100 in. below the original surface of the piece.

The indications were observed by means of magnetic particle inspection and photographed. It was found that by sus-

Fig. 6 Atomic hydrogen-welded specimens after arrested cooling and postheating for 1 hr. at 300° F.

(Top) Type 4320 filler material; (center) type 6130 filler material; (lower) type 4330 filler material

Fig. 7 Atomic hydrogen-welded specimens after arrested cooling and postheating for 1 hr. at 350° F.

(Top) Type 4320 filler material; (center) type 6130 filler material; (lower) type 4330 filler material

Fig. 8 Atomic hydrogen-welded specimens after arrested cooling and postheating for 1 hr. at 160° F. (top), 250° F. (center), and 300° F. (bottom). S.A.E.-4130 filler rod

pending the magnaflux paste in carbon tetrachloride, a clear dry impression resulted which permitted an excellent photographic record to be made. Specimens welded with certain types of stainless-steel rods were examined by both magnetic particle inspection and by acid etching.

TEST RESULTS

Crack Sensitivity vs. Postheat Temperature

The effect of postheat temperature was investigated for modified types S.A.E. 4330, 4320, 6130, 4130 and N.E.-8630 filler rods when using the atomic-hydrogen welding process. The results of this study, for the first three materials mentioned, are illustrated in Figs. 3–7, showing the degree of cracking after arresting the cooling and postheating for 1 hr. at 160, 200, 300 and 350° F., respectively. All specimens cracked when not postheated. Cracking decreased in severity with increased postheat temperature. At 400° F., no cracks could be detected and the specimens so processed were therefore not photographed. Note that after the 350° F. postheat treatment, there were still some cracks on all specimens although close examination was necessary to detect them. Had a larger number of specimens been prepared, it is possible that some would have shown cracks even at 400° F.

Figure 8 shows a group of specimens similar to those previously described but made with S.A.E.-4130 filler rod and postheated at 160, 250 and 300° F. Again the crack sensitivity decreased with increasing postheat temperature until at 300° F., magnification was required to detect the indications.

Figure 9 illustrates the results obtained when N.E.-8630 filler material was employed. In this case, the cracks were just barely detectable with magnification after postheating at 350° F.

In consideration of the above, and the difficulty in maintaining precise temperature control on a production basis with large and irregular parts, it is recommended that a postheat temperature of 600° F. be employed. We have found that 1 hr. at 600° F. is entirely effective in preventing cold cracks in these materials.

This study also indicated that while the magnitude of cracking differed with each of these steels, all had approximately the same critical postheat temperature above which no cracks would occur.

The illustrations clearly show that of the primary group, the type 4330 filler rod had the greatest crack sensitivity and the type 6130, the lowest.

The relative crack sensitivities of the types 4330 and 4320 are in accord with what might be expected in view of their carbon contents and are in keeping with the hydrogen theory. The type 6130, however, has the same carbon content as the type 4330. The lower crack sensitivity of the type 6130 may be taken to substantiate the work of Franklin,[1] wherein the influence of vanadium in reducing crack sensitivity was reported. The vanadium is believed to promote the formation of stable carbides which do not readily go into solution during the rapid thermal cycles involved during welding. It thus ties up a portion of the carbon content of the steel making it respond in a manner similar to that of a material of lower carbon content. The particles of undissolved carbides are also believed to

Fig. 9 Atomic hydrogen-welded specimens after arrested cooling and postheating for 1 hr. at 160° F. (top), 250° F. (center) and 350° F. (bottom). Type N.E.-8630 filler rod

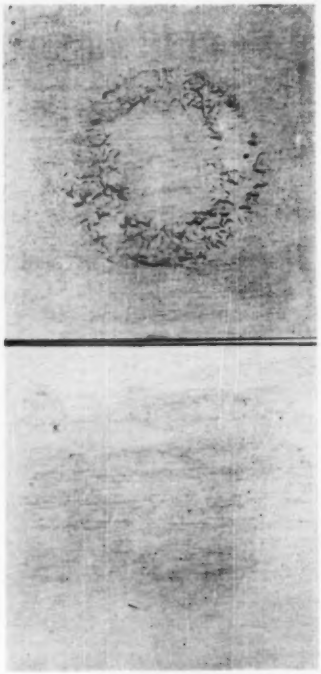


Fig. 10 Atomic hydrogen welded with type 4330 filler rod

(Top) No postheat; (lower) cooling arrested and postheating conducted for 1 hr. at 600° F.

Fig. 11 Atomic hydrogen-welded with type 4320 filler rod

(Top) No postheat; (lower) cooling arrested and postheating conducted for 1 hr. at 600° F.

form nuclei which act to speed up transformation at high temperatures.

The effectiveness of proper arrested cooling and postheating in preventing cold cracks in specimens welded with the atomic-hydrogen process can be clearly illustrated. Figures 10–12 show specimens welded with modified S.A.E.-4430, 4320, and 6130 filler rods, respectively. Figures 13 and 14 show specimens in which S.A.E.-4130 and N.E.-8630 filler rods were used. In each case, the nonpostheated specimens in the top row show numerous cracks while the postheated specimens shown in the lower rows are free of cracks.

Effect of Postheat Time Upon Crack Sensitivity

The effect upon crack sensitivity of the time for which the specimens were held at the 600° F. postheat temperature, was investigated for type 4330 filler rod.

Figure 15 illustrates the results obtained with atomic hydrogen-welded specimens postheated for 5, 10, 15 and 20 min., respectively. Specimens were also postheated for 30 and 50 min., but are not shown.

It will be observed that postheating for 20 min. was sufficient to prevent cracking with the specific materials and conditions involved. Again it is desirable to allow an ample margin for variables. Experience

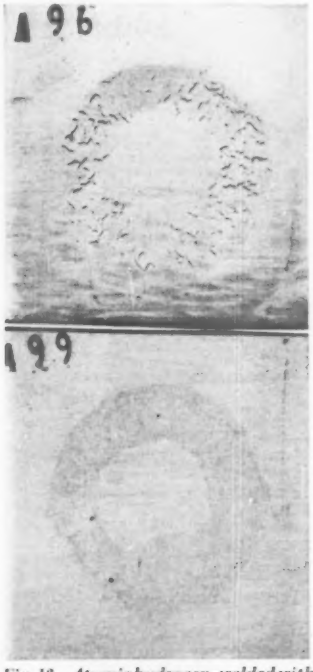


Fig. 12 Atomic hydrogen-welded with 6130 filler rod

(Top) No postheat; (lower) cooling arrested and postheating conducted for 1 hr. at 600° F.

Fig. 13 Atomic hydrogen welded with S.A.E.-4130 filler rod

(Top) No postheat; (lower) cooling arrested and postheating conducted for 1 hr. at 600° F.

Fig. 14 Atomic hydrogen welded with N.E.-8630 filler rod

(Top) No postheat; (lower) cooling arrested and postheating conducted for 1 hr. at 600° F.

Fig. 15 Atomic hydrogen welded with modified S.A.E.-4330 filler rod showing reduced cracking with increased postheating time

Cooling arrested and postheating conducted at 600° F.

has shown that 1 hr. is a satisfactory period of time. Where heavy parts are to be welded, a longer period may be required. It seems logical to believe that it will require more time for the hydrogen to escape from the center of a thick section than from a thin section. The material employed for this test was $^1/_2$ in. thick.

Crack Sensitivity vs. Time at Room Temperature Prior to Stress Relief with No Arrested Cooling and Postheating

It will be noted that reference has been repeatedly made to "arrested cooling and postheating."

The hydrogen theory and experimental evidence indicate that once the temperature of a weldment containing hydrogen is allowed to drop prematurely, even for a few minutes, cracking will occur and no amount of subsequent postheating will rectify the damage.

Cracking occurs as the temperature of the specimen drops appreciably below the established arrested cooling and postheating temperature and will continue to progress for some time after it reaches room temperature. This is indicated in Fig. 16 which shows specimens held at room temperature for periods of a few minutes, 1 hr. and 24 hr. prior to stress relieving at 1060° F. Even the parts that were stress relieved very soon after reaching room temperature contained cracks and the magnitude of the cracking increased rapidly during the 24-hr. test period.

Figure 17 shows a similar group of specimens which were refrigerated at 40° F. during the storage period. The increase in cracking was more rapid but had practically ceased at the end of 24 hr.

Figure 18 shows a $4^1/_2\times$ enlargement of a portion of Specimen A-178. The specimen was cooled to room temperature and then photographed. It was again photographed after 3 hr. and after 8 days. It was then stress relieved and again photographed. A comparison of the first two photographs shows a marked increase in the number of visible cracks (circled) and in the size of some of the cracks previously visible (arrows). After stress relieving, there was a further increase in size of some cracks. An increase in the number of visible cracks and in the size of previously visible cracks following stress relief has frequently been observed on both test specimens and production weldments not subjected to a proper arrested cooling and postheating cycle.

Figure 19 shows Sample A-179 which was processed in a manner similar to that shown in Fig. 18, except that the storage temperature was 40° F. It was observed that the cracking had essentially stabilized prior to photographing for the first time and that little additional cracking had occurred after 8 days. Apparently, however, there was a greater increase in the number of visible cracks and their size after stress relieving than in the case of specimens stored at room temperature for the same period of time.

The increase in the number of cracks is assumed to be due to microcracks which opened up to visible size. This would indicate that an appreciable amount of hydrogen remained entrapped in the weldment under very high aerostatic pressure and that the temperature gradients during stress relief raised the stress level sufficiently to increase the size of the cracks. It may be possible to alleviate this condition by raising the part to the stress-relief temperature at a sufficiently low rate to minimize the temperature gradients.

Fig. 16 Atomic hydrogen-welded specimens made with modified S.A.E.-4330 filler rod

A-154—Stress relieved soon after reaching room temperature; A-157—stress relieved after 1 hr. at room temperature; A-158—stress relieved after 24 hr. at room temperature

The tests showed that for these materials and conditions, it is important that the weldment be held within the established postheat temperature range from the time that welding is started until at least 1 hr. after the termination of the welding operation. It is also apparent that in the absence of such thermal control, stress relieving can actually increase the magnitude of cracking.

The Effect of Hydrogen Content, as Influenced by the Welding Process, Upon Crack Sensitivity

A series of specimens were prepared to verify the assumption that the cold cracks under investigation are basically caused by the rejection of dissolved hydrogen during

Fig. 17 Atomic hydrogen-welded specimens made with modified S.A.E.-4330 filler rod

A-247—Stress relieved soon after reaching 40° F.; A-155—stress relieved after 1 hr. at 40° F.; A-156—stress relieved after 24 hr. at 40° F.

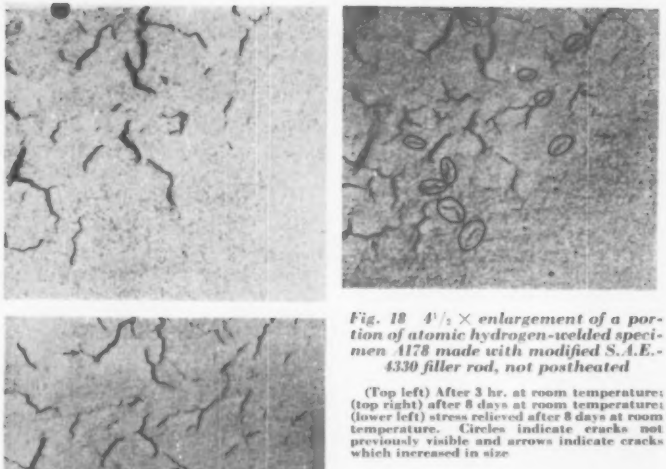


Fig. 18 4½ × enlargement of a portion of atomic hydrogen-welded specimen A178 made with modified S.A.E.-4330 filler rod, not postheated

(Top left) After 3 hr. at room temperature; (top right) after 8 days at room temperature; (lower left) stress relieved after 8 days at room temperature. Circles indicate cracks not previously visible and arrows indicate cracks which increased in size

transformation. Various welding processes were employed in order to introduce different amounts of hydrogen. None of these weldments was postheated.

The welding processes included:

1. The atomic-hydrogen process which has been widely used in the fabrication of propeller blades. This method may be expected to introduce a large amount of hydrogen into the weld bead and the heat-affected zone.

2. The metal-arc process using a lime-coated electrode. This might be expected to produce weld deposits having a moderately low-dissolved hydrogen content.

3. The submerged-arc process which employes fluxes of such nature that little if any hydrogen should be introduced into the welding zone.

4. The argon-shielded tungsten arc which should also be essentially free of hydrogen.

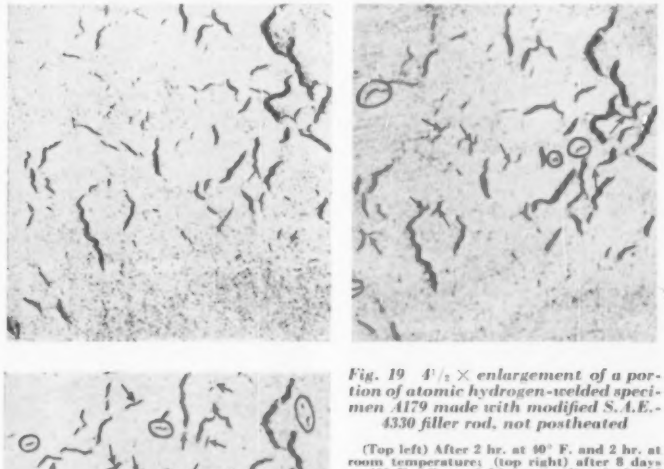


Fig. 19 4½ × enlargement of a portion of atomic hydrogen-welded specimen A179 made with modified S.A.E.-4330 filler rod, not postheated

(Top left) After 2 hr. at 40° F. and 2 hr. at room temperature; (top right) after 8 days at 40° F.; (lower left) stress relieved after 8 days at 40° F. Circles indicate cracks not previously visible and arrows indicate cracks which increased in size

The illustrations previously discussed showed the prolific cracking which occurred with the various types of filler rods when the atomic-hydrogen process was employed without postheat.

Figure 20 shows a series of specimens made with the metal-arc process without postheat.

Specimens M-117A and B were made with a special low-hydrogen electrode, developed for welding the modified S.A.E.-4320 steel. This electrode consisted of a type 4320 core wire with a lime-type coating. The illustration shows essentially complete freedom from cracks though there is evidence of some porosity. As is to be expected there are defects on each specimen due to entrapped flux at the point that the terminus overlaps the start of the weld. A different welding technique was employed on some of the later work to overcome this condition.

Specimens M-118 A and C were made in

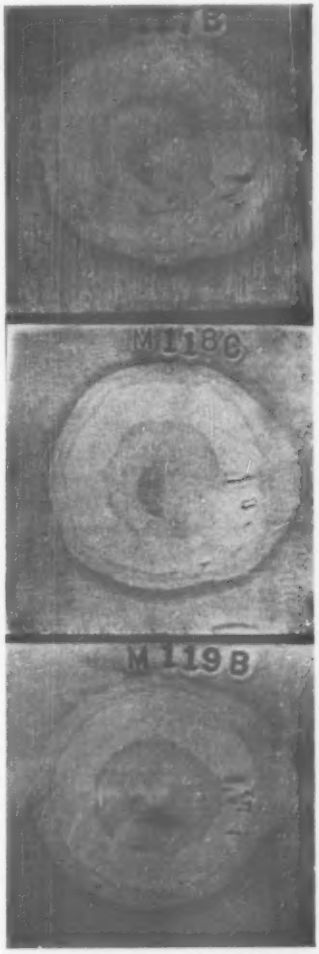


Fig. 20 Metal arc welds using special low-hydrogen electrodes, no postheat

M-117—Modified S.A.E.-4320 core wire; M-118—modified S.A.E.-4330 core wire; M-119—modified S.A.E.-4340 core wire. The visible indications are flux inclusions at the weld overlap

the same manner as the above except that modified type 4330 core wire was employed in making the electrodes.

Specimens M-119 A and B were also metal-arc welded except that the electrode consisted of the modified type 4330 core wire with sufficient carbon added to the lime-type coating to give a deposit equivalent to that of a type 4340 core wire.

It will be noted that even with the types 4330 and 4340 electrodes, cracking was not encountered at the cooling rates resulting from the air blast.

Figure 21 shows specimens welded with the submerged-arc process using types 4320, 6130 and 4330 filler rods. No cold cracks were observed on any of these specimens nor on similar specimens using types 4130 or NE-8630 filler material. There were indications due to trapped flux, particularly at the overlap of the start and finish of some of the pieces.

Surface cracks have sometimes been observed on the underside of the weld bead where the submerged-arc process has been employed for joining parts involving complete penetration of the joint. This may be due to hydrogen caused by dissociation of atmospheric moisture condensed on the part or backing material on the unprotected underside of the weld. Hydrogen flakes have been observed upon occasion, in or adjacent to submerged-arc welds. It is possible that these were caused by the contamination of the welding flux with moisture or other foreign matter which released hydrogen during the weld thermal cycle.

Figure 22 shows specimens welded with the argon-shielded tungsten-arc process which is essentially free of hydrogen. Modified S.A.E.-4320, 6130 and 4330 filler rods were employed for the pieces illustrated. It will be observed that no cracks appear on any of these specimens. Similar test pieces, welded with S.A.E.-4130 and N.E.-8630 filler rods were also crack free.

We have seldom experienced hydrogen-type cracks in weldments made with this process when using the three filler materials first mentioned. (We have not had sufficient experience with the type 4130 and 8630 materials to comment in this regard.)

Fig. 21 Submerged arc-welded specimens, no postheat

U-1382 made with modified S.A.E.-4320 filler wire; U-1383 made with modified S.A.E.-6130 filler wire; U-1384 made with modified S.A.E.-4330 filler wire

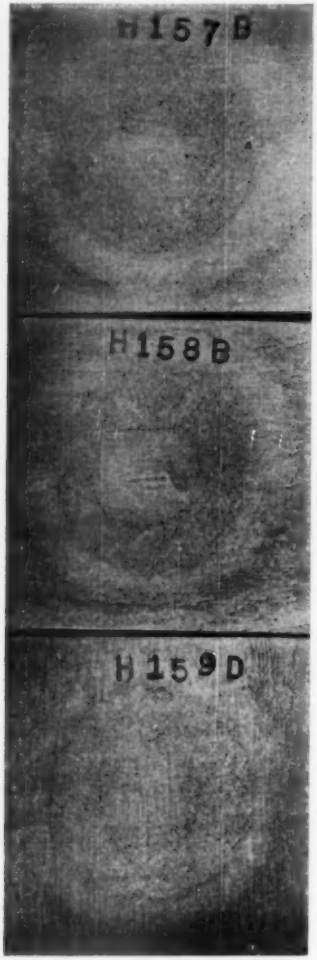


Fig. 22 Argon arc-welded specimens, no postheat

H-157 made with modified S.A.E.-4320 filler rod; H-158 made with modified S.A.E.-6130 filler rod; H-159 made with modified S.A.E.-4330 filler rod

Fig. 23 Crack-sensitivity specimens quenched in water immediately after welding; no postheat; held at 40° F., for 24 hr., stress relieved at 1060° F.; type 4330 filler rod

M-124—Metal-arc process (low-hydrogen coating); U-1386—submerged-arc process; H-162—Argon-arc process

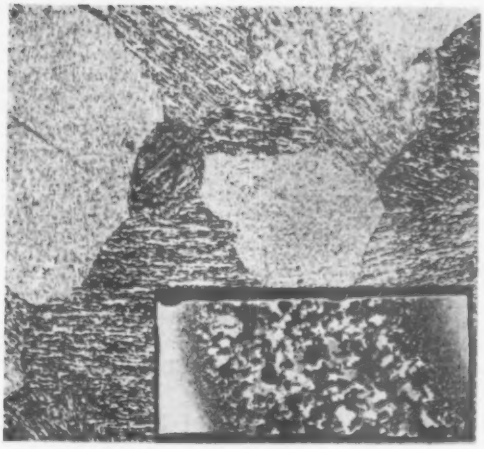


Fig. 24 Section of water-quenched argon-arc specimen

No postheat; refrigerated 24 hr. at 40° F. Stress relieved at 1060° F. for 1 hr. Etched after stress relief. Modified S.A.E.-4330 filler rod. Mag. 100 X. Insert 3 X

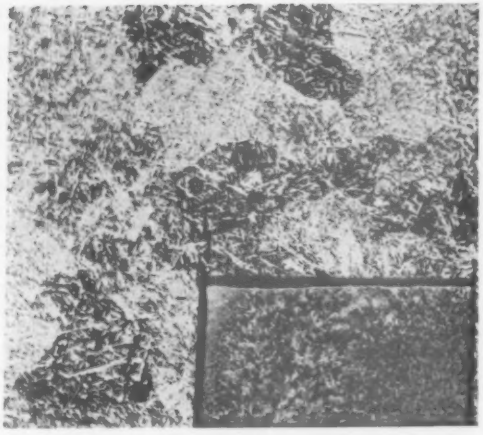


Fig. 25 Section of air-cooled argon-arc specimen

No postheat; refrigerated 24 hr. at 40° F. Stress relieved at 1060° F. for 1 hr. Etched after stress relief. Modified S.A.E.-4330 filler rod. Mag. 100 X. Insert 3 X

Cracks due to stress concentrations at the weld crater have been observed where faulty technique is employed.

These results appear to substantiate the theory that dissolved hydrogen is the prime cause of cold cracks. In its absence such cracks should not develop except possibly under unusually severe conditions of stress concentration.

The Effect of Thermal Stresses and Restraint Upon Crack Sensitivity

The previous tests indicated that even the most crack sensitive of the three subject filler materials would not crack when welded without postheat if a low-hydrogen welding process was employed. Additional tests were, therefore, conducted in order to determine whether this freedom from cracking would be retained even with drastic quenching of the specimen.

Test pieces were prepared using the three processes which did not show cracks when welded without postheat, namely metal arc, submerged arc and argon arc. Figure 23 shows the specimens which were welded with the crack-sensitive type 4330 filler rod. These pieces were all quenched in cold water immediately after welding and refrigerated at 40° F. for approximately 24 hr., followed by stress relieving at 1060° F. for 1 hr. Magnetic particle inspection revealed no cracks other than

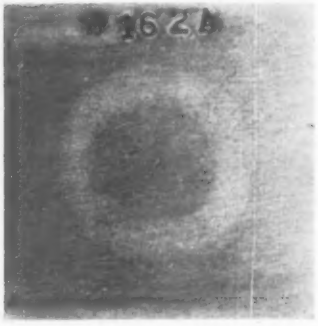


Fig. 26 Water-quenched argon arc-welded specimen after full heat treatment showing absence of magnetic indications. Compare with lower figure on Fig. 23

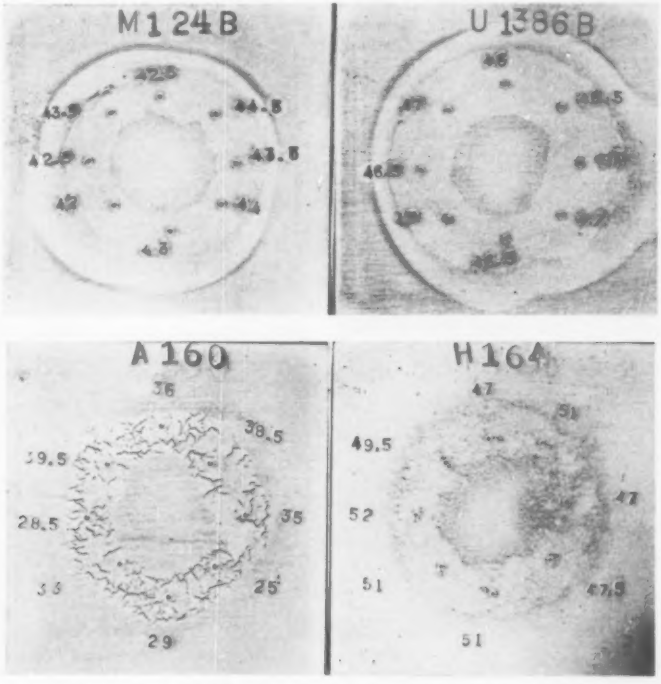


Fig. 27 Specimens welded with various processes using type 4330 filler rod. All were stored at 40° for 24 hr.

M-124B—Low-hydrogen metal-arc weld, water quenched; U-1386B—submerged-arc weld, water quenched; H-164—argon-arc weld, iced brine quenched; A-160—atomic-hydrogen weld, air cooled

the flux inclusions at the overlap points of the metal-arc welds.

The photograph shows that numerous small indications appeared on the argon-arc specimens. These were at first suspected of being cracks. Micro and macro examinations, however, showed that this condition was due to a sharply defined grain structure resulting from the high cooling rate. This is illustrated in Fig. 24 showing the specimen after etching in 2% Nital (magnified 3 × and 100 ×). The sharply defined grain structure is very noticeable.

Figure 25 shows a 3 × and 100 × magnification of a similar specimen. In this case, instead of water quenching, the standard air blast was employed which produced a much lower cooling rate. It can be readily seen that the structure in this case is less clearly defined.

It is well known that differences in structure and hardness will influence the magnetic properties of materials and this must be considered in interpreting magnetic inspection indications. To verify this, Specimen H-162-A which showed the magnetic indications, was fully heat treated as follows:

Normalized at 1600° F. for 1/2 hr.

Heated at 1600° F. for 1/2 hr. and oil quenched.

Tempered at 1060° F. for 1 1/2 hr. and air cooled.

After this treatment no magnetic indications were visible as shown in Fig. 26. The reason that the argon arc-welded specimens were the only ones which showed the clearly defined grain structure is not known.

The results of the quenching tests substantiate the theory that in the absence of dissolved hydrogen, thermal stresses during rapid cooling and transformation are not the primary causes of cracks but are only responsible for their propagation.

The Influence of Hardness of the Weld Deposit Upon Cold Crack Sensitivity

The relation between weld hardness and cold crack sensitivity was investigated because of the widespread belief that cold-crack sensitivity increases with increasing hardness of the weld deposit.

Specimens were welded with the low-hydrogen metal-arc, submerged-arc, argon-arc and atomic hydrogen processes. The first two groups were water quenched and the third quenched in iced brine immediately after welding, as it had already been determined that cracking would not result with weldments so hardened. The atomic hydrogen-welded specimen was air cooled because it was shown by experience that cracking would occur even at the relatively slow cooling rate thus resulting.

Type 4330 filler rod was used for all test welds. The specimens were held for approximately 24 hr. at 40° F. after welding but none were stress relieved in order that a hardness survey could be made in the "as-welded" condition. After magnetic particle inspections, the pieces were photographed. The results are shown in Fig. 27.

The specimen with the lowest hardness was that welded with the atomic-hydrogen process, the range being from 25 to 39.5

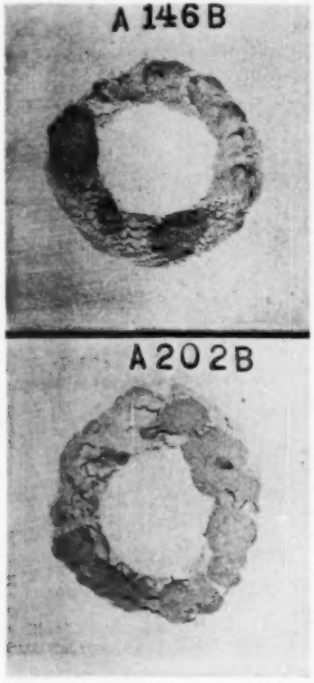


Fig. 28 Atomic-hydrogen weld, type 410 + Mo stainless-steel filler rod

(Top) Standard cooling, refrigeration and stress relief, no postheat; (bottom) cooling arrested and postheating conducted at 350° F. for 1 hr.

Fig. 29 Atomic-hydrogen weld, type 410 + Mo stainless-steel filler rod

(Top) Cooling arrested and postheating conducted at 600° F. for 1 hr.; (bottom) cooling arrested and postheating conducted at 700° F. for 1 hr.

Fig. 30 Specimens welded with various processes using type 410 + Mo stainless filler rod; all subjected to standard cooling and stress relief, no postheat

A-163—Argon-arc weld; M-123—Low-hydrogen metal-arc weld; U-1365—Submerged-arc weld

Rockwell "C." The photograph shows that this piece contains a very large number of cracks.

The other specimens were all much harder. The hardest was that welded with the argon-arc process and brine quenched. This piece ranged from 47 to 52 Rockwell "C." None of this group were cracked however.

The results of the tests would seem to confirm that in the absence of dissolved hydrogen, the relative hardness of the weld deposit is not a controlling factor influencing cold cracking of the weld bead or the heat-affected zone.

Cracking in Weldments Made with Stainless-Steel Filler Rods

Crack-sensitivity studies were made of groups of specimens welded with several kinds of stainless-steel filler materials. One group was welded with the atomic-hydrogen process using type 410 + Mo filler rod. It was found that this material required a higher postheat temperature than the 6300 and 4300 series previously studied, and that the temperature range was much more limited.

Figure 28 shows that when not postheated, weldments made with type 410 filler rod developed numerous cracks (see specimens A-146-B). When cooling was arrested and postheating conducted at 350° F., serious cracking still occurred, (specimen A-202-B). Cracking was very slight with the 4300 and 6300 steels at this temperature. It was not until a postheat temperature of 600° F. was employed that cracking was eliminated with the type 410 filler rod as illustrated in Fig. 29 (specimens A-230-B). When the postheat temperature was raised to 700° F., however, cracking again occurred as shown on specimens A-232-B. Cracking became progressively worse as the postheat temperature was increased. It is quite evident that very accurate control of the arresting and post-heating temperature is essential with this material. It seems logical to assume that by employing a very slow cooling rate, the detrimental effects of excessive postheat temperature can be minimized.

Further tests were made to determine the crack sensitivity of the type 410 filler rod when deposited with low-hydrogen welding processes.

Figure 30 shows a series of specimens welded with the argon-arc, metal-arc, (with lime-coated electrodes) and submerged-arc processes. None of these specimens were postheated, all having been subjected to the standardized cooling, refrigerating and stress-relief treatments. As is quite evident from the photograph, cracks did not develop in any of these specimens.

Figure 31 shows a group of specimens atomic-hydrogen welded with the nonmagnetic types 347 and 310 stainless steels. No postheating was employed. Because of the uncertainty of magnetic particle inspection when using stainless-steel filler materials, these specimens were hot etched in 50% HCL in water. A series of indications were observed in the Type 4320 parent metal at the junction of the weld bead. While this might be due to underbead cracking, the radial position of the lines was not characteristic of such a condition. It was considered that the hot etching may have caused the indications. To check further, a second series of test specimens was prepared and subjected to magnetic particle inspection which would be satisfactory for examining for cracks in the parent metal.

Figure 32 shows that no radial cracks were visible in the parent metal. There were numerous indications in the weld bead due to the magnetic discontinuities resulting from the dilution of the nonmagnetic filler material with the magnetic material from the plate. This condition made it difficult to determine the condition of the weld bead with any degree of certainty.

The same four specimens were hot etched and re-examined. Figure 33 shows that the radial indications in the parent metal are not apparent in this instance.

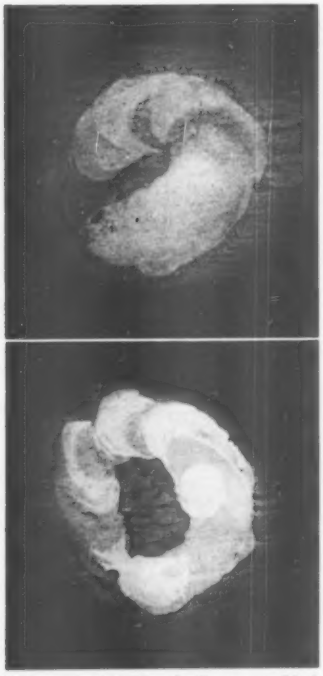


Fig. 31 Atomic hydrogen-welded specimens, no postheat, 50% hot HCl etch inspection

A-144 welded with type 347 stainless steel and A-145 welded with type 310 stainless steel

Fig. 32 Atomic hydrogen-welded specimens, no postheat, magnetic particle inspection

A-161 welded with type 347 stainless steel and A-162 welded with type 310 stainless steel

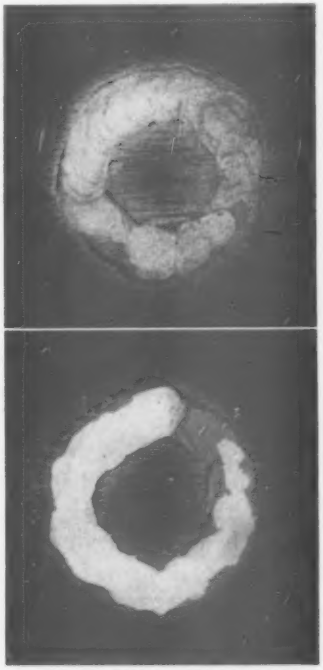


Fig. 33 Atomic hydrogen-welded specimens, no postheat, 50% hot HCl etch inspection

A-161 welded with type 347 stainless steel and A-162 welded with type 310 stainless steel

There are, however, indications in the weld deposits of most of the specimens which may be due to cracks. The study of this group was not carried further.

PRACTICAL APPLICATION

For the specific materials which were studied, it would appear that cold cracks can be effectively controlled by the application of the findings outlined in this paper. These consist basically of the following factors which are listed in the order of their importance:

(*a*) Use effective arrested cooling and postheat procedures which prevent the weld from dropping below 600° F. from the time that welding is started until at least 1 hr. after completion of welding.

(*b*) Prevent hydrogen from being dissolved in the weld zone through the use of suitable low-hydrogen welding processes and techniques.

(*c*) Make use of steel plate and filler rod materials which contain carbide stabilizing constituents that will speed up transformation of austenite through the phenomenon of nucleation and which will make part of the carbon ineffective during the very high speed thermal cycles involved during welding.

It is not claimed that the temperature and time cycles mentioned in this paper will apply to all types of hardenable steels. It seems reasonable to assume, however, that the basic principles will apply. A study of the time, temperature, transformation curves for each type of steel should give a first approximation of the proper thermal time cycle for arrested cooling and postheating. From this the proper conditions can be established to insure that transformation is more nearly completed at the proper elevated temperature.

It is evident that much work remains to be performed before a thorough understanding of the phenomenon of cold-crack formation in weldments can be attained.

If this paper contributes in some small part to the extension of the current understanding of the causes of cold cracks, and if further investigation is thereby encouraged, the efforts spent in its preparation will be well repaid.

ACKNOWLEDGMENT

The authors wish to acknowledge interest and support of W. C. Schulte, Chief Metallurgist, without which this work could not have been undertaken. The active cooperation of the members of the Welding Research Laboratory and its parent Metallurgical Department made possible the preparation and examination of the specimens.

Welding of most of the specimens was performed by D. Henry with the exception of those made with the submerged-arc process by J. Smith.

References

1. Franklin, F. F., "Use of Carbide-Stabilizing Elements to Improve Weldability of Plate Steels," The Welding Journal **27** (1), Research Suppl., 20-s to 26-s (1948).

2. Hoyt, S. L., Sims, C. E., and Banta, H. M., "Metallurgical Factors of Underbead Cracking," *Metal Technol T. P. 1847*, June 1945; *Ibid.*, Also in The Welding Journal, **24** (9) Research Suppl., 433-s to 445-s (1945).

3. Herres, S. A., "Practical Importance of Hydrogen in Metal arc Welding of Steel," *Trans. A.S.M.*, **39** 139 to 188 (1947).

4. Rollason, E. C., "The Influence of Hydrogen on Weldability of High-Tensile Steels," The Welding Journal, **23** (11), Research Suppl., 604-s to 605-s (1944).

5. Voldrich, C. B., "Cold Cracking in the Heat-Affected Zone," The Welding Journal **26**, (3), Research Suppl., 153-s to 169-s (1947).

6. Stern, I. L., Kalinsky, J., and Fenton, E. A., "Gas Evolution from Weld-Metal Deposits," *Ibid.*, **28** (9), Research Suppl., 405-s to 413-s (1949).

7. Sims, C. E., and Banta, H. M., "The Development of Weldable High-Strength Steels," *Ibid.*, **28** (4), Research Suppl., 178-s to 192-s (1949).

Welding in Engineering Education

(*Continued from page 751*)

tures and machinery, where its requirements and possibilities ought to be given the same weight as those of casting and riveting.

After all, it is the designer who—by means of his drawings—issues the fundamental technical specification of a job to the workshops, and he can only produce an efficient design for welding if he has a sound knowledge of its implications.

The old method of producing a design and adapting it for welding is fortunately dying out. Once a designer has decided on using welded construction his work has to be laid out accordingly, the arrangements of gears and mechanisms, the layout of framed structures, etc. have all to be based on the requirements of the welded design.

At the Manchester College of Technology, apart from a course of Welding Engineering a series of lectures on welding technology and welding design (Koenigsberger, F., "Training the Welding Engineer," Welding Journal, April 1949) is now incorporated in courses on strength of materials, design of structures and machine design for University Students in Mechanical and Structural Engineering. These lectures appear to be welcomed by the Students.

This seems to be the way to give welding its rightful place in all fields of engineering, and in turn should result in production which is technically efficient and economically competitive.

Cutting Cast Iron

by R. L. Vining

THERE is a special cutting technique which is used to cut cast iron with a standard oxyacetylene blowpipe. Operators have been using it for years. Here is how it is done.

Adjust the cutting oxygen at the regulator to give working pressure twice that recommended for cutting steel the same thickness. Keep the blowpipe cutting-oxygen valve open while setting this pressure on the regulator, then close it.

Light the blowpipe, then adjust the heating flames to an excess of acetylene. Again, make the adjustment with the cutting-oxygen valve open. The length of the excess acetylene feather should be about two to two and one-half times the length of the inner cone.

R. L. Vining, The Linde Air Products Co., Birmingham, Ala.

Fig. 1 Here is a special technique for cutting cast iron

Move the blowpipe in semicircular arcs to provide more heat

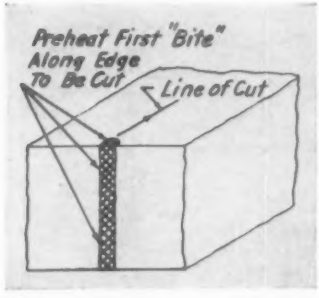


Fig. 2 First preheat vertically what will be the first "bite" of the cutting blowpipe

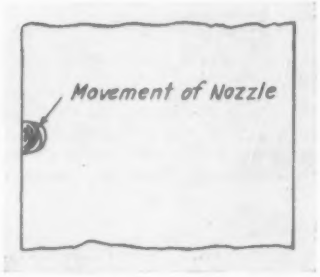


Fig. 3 Start at the top and swing the blowpipe in short arcs until the metal begins to "boil"

CUTTING TECHNIQUE

Now close the cutting-oxygen valve again, and heat the edge to be cut from top to bottom, see Fig. 2. You are preheating what will be the first "bite" of the cutting blowpipe throughout the entire thickness of the metal. By warming this part of the casting, the cut starts more quickly and more easily. The warmer the whole mass of iron is heated the easier it will be to cut.

Fig. 3 shows the top view of the edge to be cut. After you heat the edge, direct the blowpipe at the starting point at the top and swing the nozzle in short arcs across the line of cut. Hold the blowpipe so the inner cones of the flame (not the excess acetylene cones) are about $\frac{1}{8}$ to $\frac{1}{4}$ in. above the surface of the casting. A spot about the size of a dime is heated until the metal "boils."

When the metal begins to bubble open the cutting-oxygen valve a little and blow off the slag. Then move the nozzle just over the heated edge, open the cutting-oxygen valve wide, and begin to move the blowpipe along the line of cut. Hold the nozzle at an angle of about 45° to the surface and use the same swinging motion.

When the cut goes all the way through to the bottom of the part,

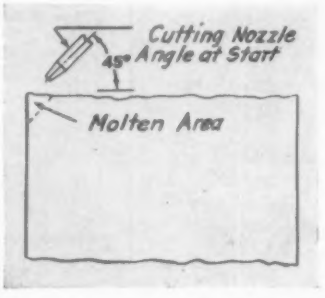


Fig. 4 When the cut is started, the blowpipe is held so the nozzle makes an angle of about 45° with the surface

Fig. 5 As soon as the cut reaches the bottom of the part, the blowpipe is straightened as shown here

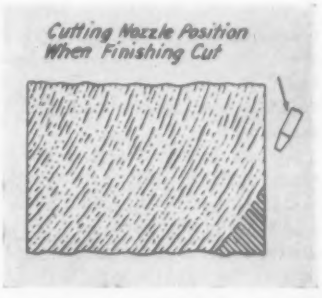


Fig. 6 The blowpipe is kept at the same angle as the angle of the lag until the cut is completed

straighten the blowpipe until it is at an angle of about 75°. Once the cut is started, the metal is preheated enough by the cutting reaction for the cut to go forward.

In cast-iron cutting, there wi l always be some lag, even if the blowpipe is straightened up to 90°. However, by straightening the blowpipe the cut might be lost.

At the far edge, carry the blowpipe over the edge and down across the outer surface. Hold the blowpipe at about the angle of the lag so that this part is cut through, Fig. 6.

If you lose the cut, move the blowpipe nozzle back along one edge of the kerf about $^1/_2$ in. and lap that edge and the point where the cut stopped. Use the same swinging motion. Then reheat the point where the cut stopped and start the cut again in the same manner as at the start (see Fig. 7).

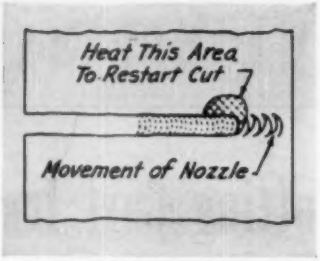


Fig. 7 If the cut is lost, reheat just as if starting a new cut

FLUX CUTTING

You can get more heat into the cut by using a steel welding rod when you cut cast iron. Where the slag does not flow easily, a steel rod will make the job easier. The slag from the rod mixes with the slag from the cast iron and increases its fluidity so that it is easy to blow-off. The rod is fed into the cut.

PROTECT YOURSELF

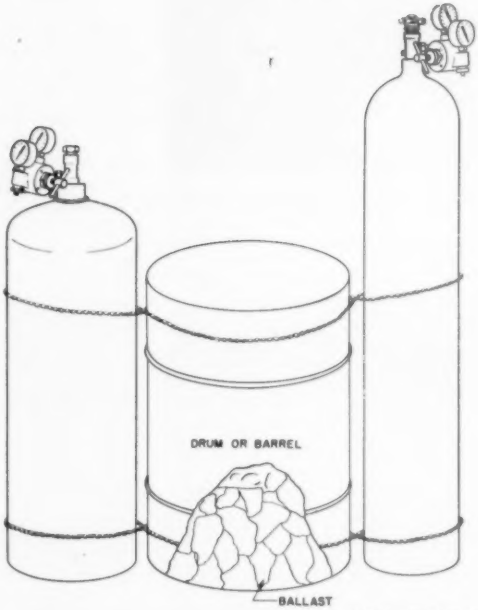
Remember that cast-iron cutting is a much hotter job than cutting steel. If you try this technique for cutting scrap or for small cast-iron jobs, always protect yourself. There will be plenty of sparks and lots of slag coming off the work. Always wear heavy asbestos gloves and suitable woolen clothing. And keep your legs and feet protected from the molten slag.

Always provide protection against heat and sparks before starting work, so you won't have to stop during the cutting job. Cast iron cuts best when it is very hot. If you stop in the middle of a cut, the work will cool down and it will be even more difficult than at the start.

Using Barrels as Gas-Cylinder Supports

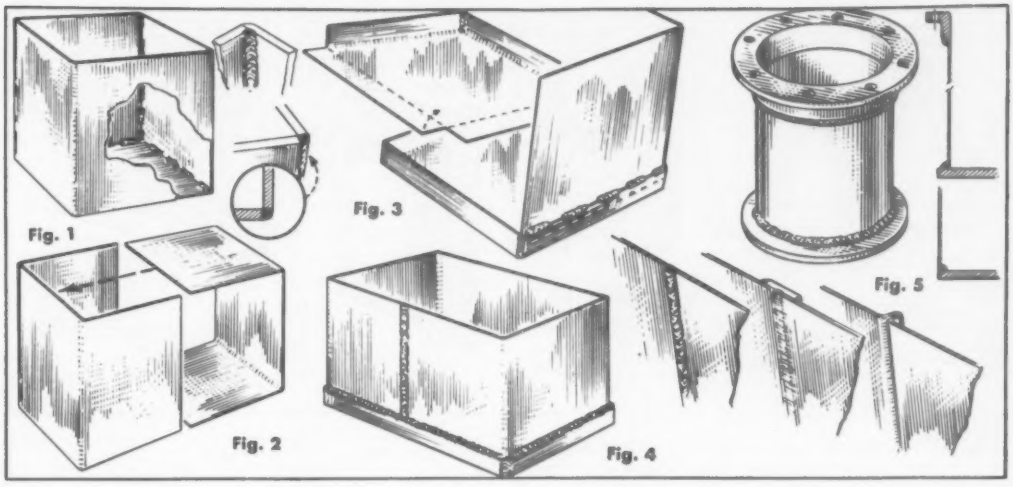
A well-built gas-cylinder truck is usually the ideal support for gas cylinders and has the advantage of added mobility. These trucks should always be used wherever possible as insurance against cylinders falling and sustaining injuries. This is especially true in the case of acetylene cylinders which should always stand in an upright position. There are occasions, however, in construction or field work where the terrain is rough or the work is carried on at a different level, where the use of a cylinder truck is impractical. In cases such as these, Fig. 1, shows a safe and easy way to make a barrel or drum, and two pieces of rope or link-chain does the trick when no adequate vertical support is available.

A clean drum or barrel, free of all grease and oil, is placed at the spot where the cylinders are to be located and filled from $^1/_4$ to $^1/_2$ full of ballast. Ballast may consist of any available material such as rocks, sand, dirt or water. By using water as a ballast and adding a bucket, the barrel may also be used as a fire extinguisher. With the barrel anchored firmly in place, the cylinders are positioned against the barrel and lashed to the drum.



Courtesy Air Reduction Sales Co.

Fig. 1. Ballast barrel used to support cylinders



Ideas for Designing Housings and Covers

Thought starters on welded design suggested by The Lincoln Electric Co.

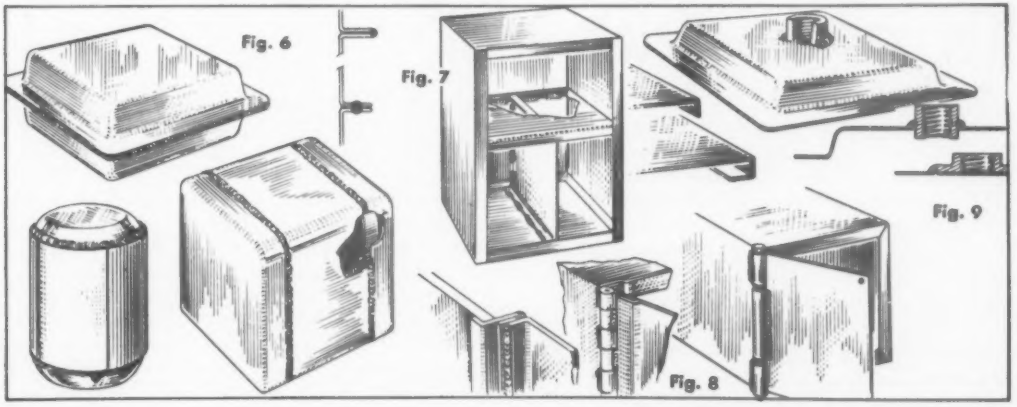
As shown in the following examples, arc welding provides the designer with unlimited flexibility when it comes to producing machinery housings and covers at low cost. Different types of construction can easily be utilized depending on the basic requirements of the part, the appearance desired, the quantity to be produced and the shop equipment available for fabrication. Through welded construction, the designer can also eliminate possibilities for accidental breakage as with cast iron or looseness as common in riveted designs.

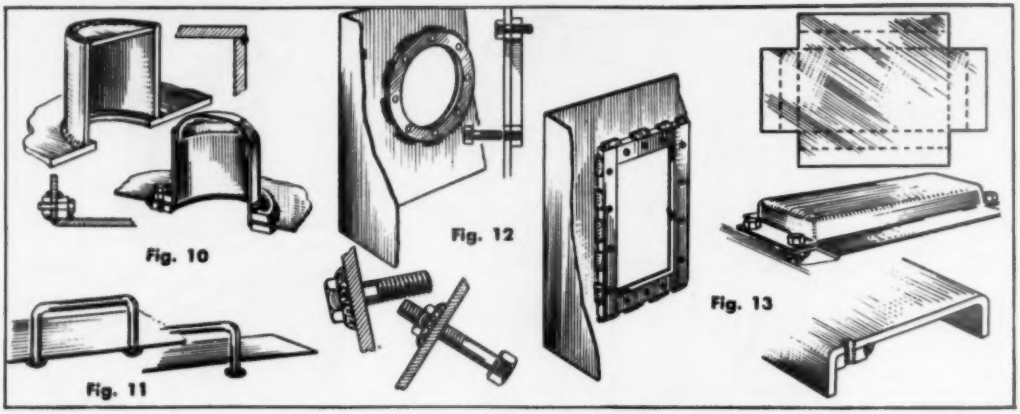
The simplest type of container (Fig. 1) is fabricated from plain sheet, sheared to size and welded with intermittent welds on the inside or with a solid corner weld on the outside. Two pieces can be bent as in Fig. 2, to cut the amount of welding needed. The fit-up of simple containers can be simplified further by bending the edges in a brake (Fig. 3) making welding easier by minimizing the danger of burn-through on light gage metals.

The sides of the container can be bent as in Fig. 4, also reducing the amount of welding necessary. The joint can be a plain butt weld or a back-up strip tacked to one side for easier fit-up and welding. The joining surfaces also can be bent for fast, easy edge welding. A plain steel strap welded to the bottom or top provides added strength and improved appearance.

The container sides can be rolled from a single piece (Fig. 5) and welded as indicated above. A rolled-steel strip or angle added to the top can be used for bolting on a cover if desired. The bottom piece can be fillet welded inside or outside, depending on the diameter of the container and the appearance desired.

Two formed sections welded together (Fig. 6) produce totally enclosed containers as for fluid storage tanks. The mating surfaces may be edge welded or welded through with automatic submerged arc welding. A similar tank can also be





fabricated from formed heads and a rolled cylinder or tubing depending on the size. The heads are telescoped inside the cylinder and lap welded for pressure tightness and appearance.

Another type of construction is to use two formed ends and a plain center. The center piece can be offset to fit under the formed ends or a back-up strip tacked to the center section to simplify fit-up and welding.

Partitions are simply formed from plain sheet as in Fig. 7. A single bend or double bend is used, depending on the strength and appearance required.

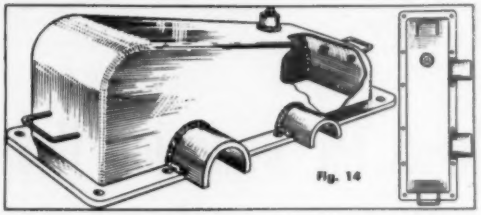
Hinged doors, sheared or formed to shape, can be provided with simple hinges as in Fig. 8. One type of hinge is made from plain, small diameter pipe. Where long doors are involved, piano-type hinges or plain hinge sections are welded to the housing and to the door.

Connections or take-offs for fluids (Fig. 9) are made by arc welding standard pipe fittings to the containers. The fittings can be simply positioned on the top or inserted in a punched hole and fillet welded.

Where housing extensions are required, they can be made from tubing or formed steel as in Fig. 10. The end of the tubing can be covered by a plain disk, butt welded to the tubing wall. Similarly a dished head can be used, fitting inside the tubing and lap welded in place. The extensions can be fillet welded to the container wall or a ring used where bolted construction is desirable for easy removal at any time.

Handles are easily made from plain bar stock bent and welded as in Fig. 11. When it becomes desirable to have the handles loose, washers can be welded to the ends of the bar stock.

Bolting rings or adaptors providing sufficient metal for securely holding bolts can be welded on the inside as in Fig. 12. Cap screws or nuts can also be welded from the inside for bolting on parts.



Covers may be plain sheared stock or formed as in Fig. 13. Washers or plugs, often desirable where bolts are used, distribute the pressure of each bolt over a wider area.

The typical gear case shown in Fig. 14 incorporates many of the fundamental requirements for this type of machine part. Light weight, yet rugged construction, provides maximum durability for the severest of service.

Annual Meeting Program
Given in this issue

Why and How Metals Break

NEW theories as to why and how metals break, which have a bearing on a longer life for cut flowers and the height of giant California redwoods, have been revealed.

Investigations by scientists of the General Electric Research Laboratory show that the fracture of metals begins with extremely small cracks, nuclei which grow into a large split when enough tension is applied. Prior to this investigation, it was usually assumed that the break in the metal occurred instantaneously throughout the sample, the scientists explained.

The metals study was begun with research into how a column of fluid breaks. It soon became apparent that bubbles, which break a water column, have much in common with cracks in metal, it was pointed out.

If a pull is applied to a column of fluid or a bar of metal, the column or bar will hold together if the tension is not great enough to do the work of making the nuclei (bubbles or cracks) grow into a break. For every tension there is a critical bubble or crack size.

Reprinted from *Welding Arcs*, June 1949.

If, when a certain tension is applied, there are nuclei of the critical size or larger, they will grow rapidly, causing the sample to break. However, nothing will happen if only nuclei smaller than critical size are present, according to the scientists. The smaller the nucleus, the bigger the force needed to expand it into a break, they said.

The giant California redwoods give a good example of how much tension a fluid can stand without breaking, according to the scientists. The larger redwoods pull columns of water in their trunks as high as 300 feet above the ground, under a tension of about 130 pounds per square inch. Water under so low a pressure would be expected to boil. But if this were to occur in a tree, the column of sap would be broken, and the tree would die. The redwoods survive because there are no nuclei of the critical size for the 130-pound tension exerted on the sap, the scientists explained. Before the boiling process in fluids or the breaking process in metals can take place, there must be nuclei, the G-E researchers said.

When a flower is cut in the garden, a super-critical nucleus is introduced into the bottom of the stem, growing quickly into bubbles which block the stem's water columns. It is then impossible for the flower to suck up water from a vase, so the flower soon wilts. However, the scientists suggest that those flower fanciers, whose mothers didn't tell them the trick, cut off the bubble-blocked portion of the stem under water in the vase. The column is thus restored and the flowers will live considerably longer.

Spiral Tubing Produced by "Heliarc" Welding

SPIRAL welding tubing of stainless steel, Inconel and plain carbon steel has been made by the B & M Manufacturing Co. of Grand Rapids, Mich. Tubing of almost any diameter and thickness can be easily produced by forming into a closed spiral and welding the joint with a "Heliarc" torch. The same process and equipment can be used to making tubing of brass, aluminum or even magnesium. Diameters range from $^1/_4$ to 3 in. and walls from 0.015 to 0.0625 in. or more. The forming machines are simple and light—no heavy equipment or forming dies are used.

Particular advantages of this process are the speed and the adjustable feature that permits tube of different size and thickness to be welded with only a few adjustments of the forming head and welding machine. Coiled strip of proper width is placed on the forming machine and forced through a die that makes the spiral. As the tube emerges from the die it passes under the "Heliarc" torch and the seam is automatically welded. The tube can then be given a cold draw to produce a perfectly smooth surface.

Inert gas-shielded arc welding is particularly adapted for this type of work. Due to the high intensity of the arc, welding is rapid and there is practically no distortion. Welds are of excellent quality and there is no flux to remove after welding.

The tube shown in Fig. 1 is made of 19-gage, Type 304 stainless steel. Flat strip $^3/_4$ in. wide makes a spiral $^3/_8$ in. in diameter. For certain applications, hydrogen is burned inside the tube to prevent oxidation.

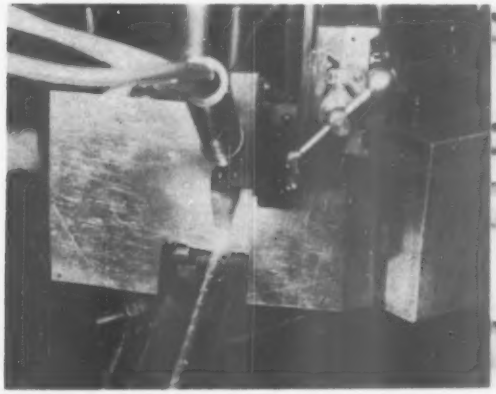
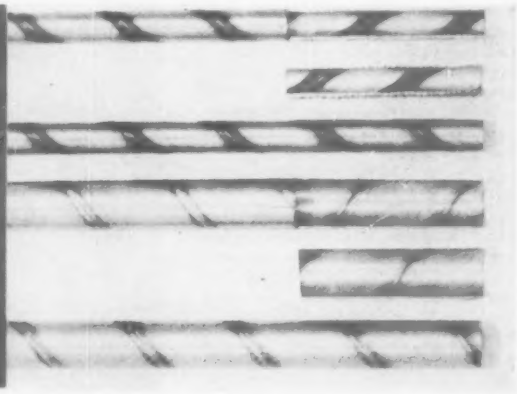


Fig. 1 "Heliarc" welding spiral tube of stainless steel



Photos courtesy The Linde Air Products Co.

Fig. 2 (Above) Stainless steel tube, $^1/_4$ in. diameter, 19 gage thick—no hydrogen backup. (Below) $^5/_{16}$-in. diameter tube, 28 gage thick, with hydrogen backup

Helium vs. Argon for Welding of Aluminum

One gas is not as good as another for automatic inert arc welding of aluminum

by A. J. Last

IN THE fabrication of Bowen electrically heated aluminum hot-water tanks for trailer coaches, the Handling Equipment Mfg. Corp. of Wixom, Mich. uses a 400-amp. General Electric Inert-Arc welder with crater filler attachment.

Figure 1 shows the component parts of one of their tanks. The two half stampings are made of 38H14 aluminum. The ring is an extrusion of 43 S aluminum. Careful design as to the shape of this extrusion allows it to serve a dual purpose. First it acts as an effective backup and secondly it provides the proper amount of filler metal to the joint. The completed tank in an aluminum case is shown on the left.

Figure 2 shows the fixture for holding the nipples in place for manual welding. As shown, the stamping is in the horizontal position. The fixture is attached to a hinge that lets the operator change the position to the vertical as the weld progresses around the tube. On the completed tank is shown a unique method of attaching a stud. An aluminum U-shaped clip with a hole in the center is slipped over the square head machine bolt and then welded to the tank. In both of these welds the crater filler attachment, that automatically reduces the current when necessary, is an invaluable aid to the operator in making strong and neat appearing welds.

Figure 3 shows the fixture for welding the two stampings together.

Accurate records maintained by Handling Equipment Mfg. Corp. on gas consumption have revealed some interesting results. When they first went into production Argon gas was used exclusively and the following information was recorded.

1. The electrode was connected to the 100-v. tap on the welder.

2. The welding current was 350 amp., which was the maximum current the

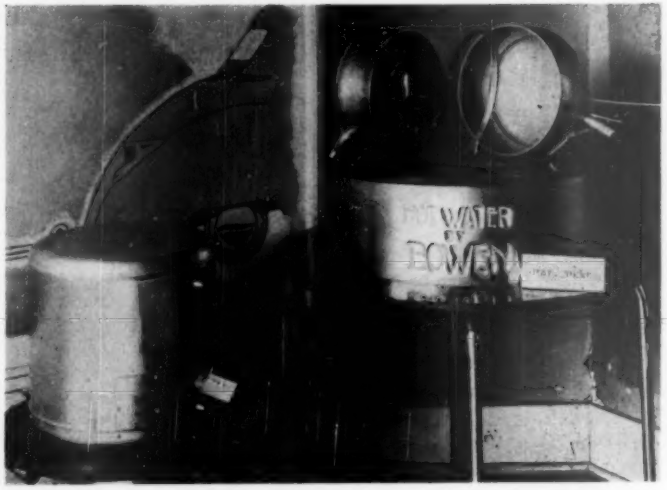


Figure 1

Figure 2

A. J. Last is with the Welding Sales & Engineering Co., Detroit, Mich.

$^3/_{16}$-in. diameter tungsten would withstand without balling up.

3. One-fourth-in. diameter tungsten could not be used to take advantage of the 400 amp. output of the welder because it made the bead too wide.

4. At 350 amp. with Argon the welding speed was 16 ipm.

5. The gas consumption was 15 cu. ft. per hour.

In an attempt to get a faster welding speed Helium gas was tried and the following results noted.

1. When the first tank of Helium was used the electrode was connected to the 100-v. tap, which was the same tap as used with Argon.

2. With this connection the Helium consumption was 40 cu. ft. per hour.

3. The welding speed about the same as Argon.

4. The electrode connection was changed to the 150-v. tap with the following results.

A. 250 amp. of current used with $^3/_{16}$-in. tungsten.

B. Gas consumption reduced from 40 cu. ft. per hour to 19 cu. ft. per hour.

C. Welding speed increased from 16 ipm. to 26 ipm.

D. Weld beads were narrower with deeper penetration, and also higher with more reinforcement, than welds made with Argon.

Figure 3

The Handling Equipment Mfg. Corp. hydrostatically tests all tanks at 300 psi. pressure. In their opinion the Helium welds, which are narrower and have more reinforcement, are stronger than the Argon welds with wider and flatter beads. Argon gas is still used for manual welding because it is easier for the operator to manipulate the arc.

Seesaw

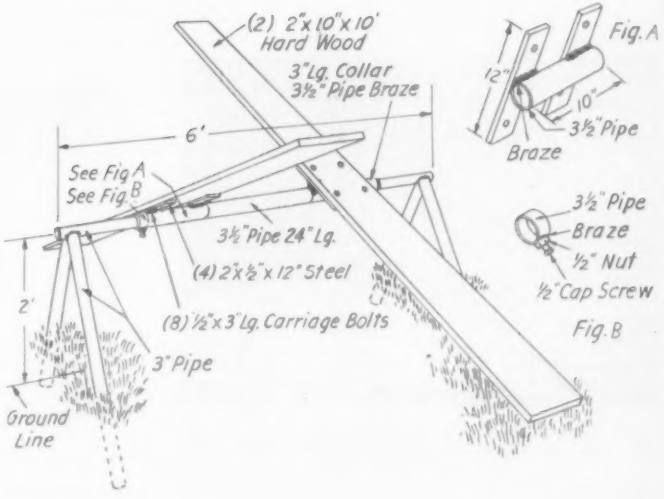
by H. C. Bell

THIS seesaw helps to keep little tots happy. It's easily made from materials you have around the shop.

Two 2- by 10-in. planks, 10 ft.-long, make the teeters. They are fastened to supports made from $3^1/_2$-in. pipe and strap iron. Two pieces of strap iron are brazed to the pipe as shown in Fig. A. The teeters are held in place by a spacer and two collars. These are also made from $3^1/_2$-in. pipe, 3-in. pipe is used for the crosspiece and the legs.

All parts were braze welded. The low heat required for braze welding makes it a fast, economical welding method.

H. C. Bell, The Linde Air Products Co., Salt Lake City, Utah.



Disappearing Welds

Special welded truck bodies are finished with body solder

by M. L. Powers

ONE auto body and fender shop has gone into the business of building special truck bodies of all-steel construction. And although many of the fabricating operations consist of oxyacetylene welding, all the welds disappear—solder applied over the welds makes them completely "invisible." Here is how they do it quickly and efficiently (see Figs. 1–5).

M. L. Powers, The Linde Air Products Company, Kansas City, Mo.

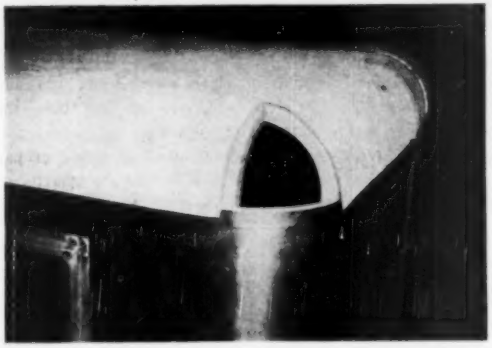


Fig. 1 One of the welding operations consists of welding a sheet-metal corner section to the body panel

A small neutral flame is used to make the weld. Where the sheets overlap, the weld is made by melting the edges

Fig. 2 After an inch or two of the weld is completed, the weld metal is hammered and depressed to receive the body solder

Steel welding rod is used

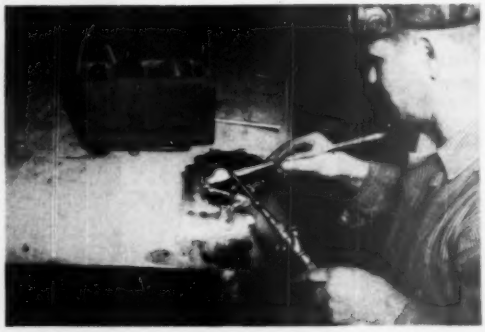


Fig. 3 Weld areas are then ground and painted with muriatic acid cut with zinc, and the cleaned surfaces are tinned with body solder

Following tinning, body solder is applied

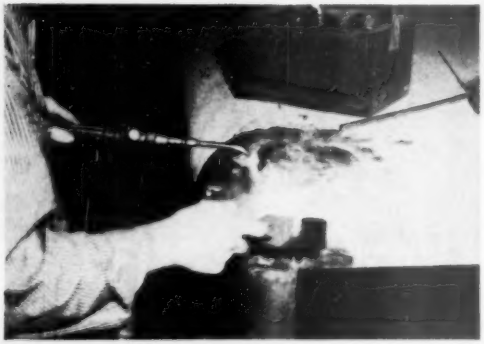


Fig. 4 For all soldering operations, the flame is long and bushy with a heavy excess of acetylene

The solder is kept mushy, so it can be smoothed with a wooden paddle

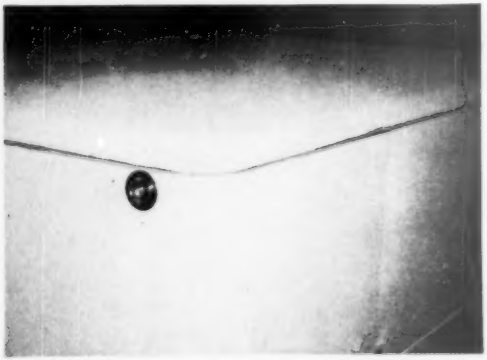


Fig. 5 Just enough heat is used to keep the solder in a pasty condition

Final operations consist of grinding and painting

Welded Television Tower and Antenna

by Otto R. Bradshaw

TALK about spare time jobs—one welding operator built a television tower and antenna during his slow periods, Fig. 1 shows the 30-ft. tower and 10-ft. antenna.

The tower was built from thin-wall electrical conduit and welding rod. All the joints were braze-welded—bronze rod and Brazo flux tinned perfectly to the galvaneal coating of the conduit. Construction of the tower is shown in the sketch, Fig. 2.

The tower legs are hinged to angle iron frames which are anchored to the roof as shown in the sketch. The tower was raised by first hinging two of the legs to one angle frame. Then the tower was pushed up with a notched pole, and the third leg secured. The angle frames held the tower during winds up to 80 miles per hour even before 3 guy wires were added for safety.

The 10-ft. antenna was made from $^1/_2$-in. aluminum tubing. Joints were fusion welded using a soft flame. An excess acetylene flame was used to keep oxide from forming too rapidly during welding. The antenna can

Otto R. Bradshaw is connected with the Bradshaw Weldors Supply Co., Waukesha, Wis.

Fig. 1 Welded television tower and antenna

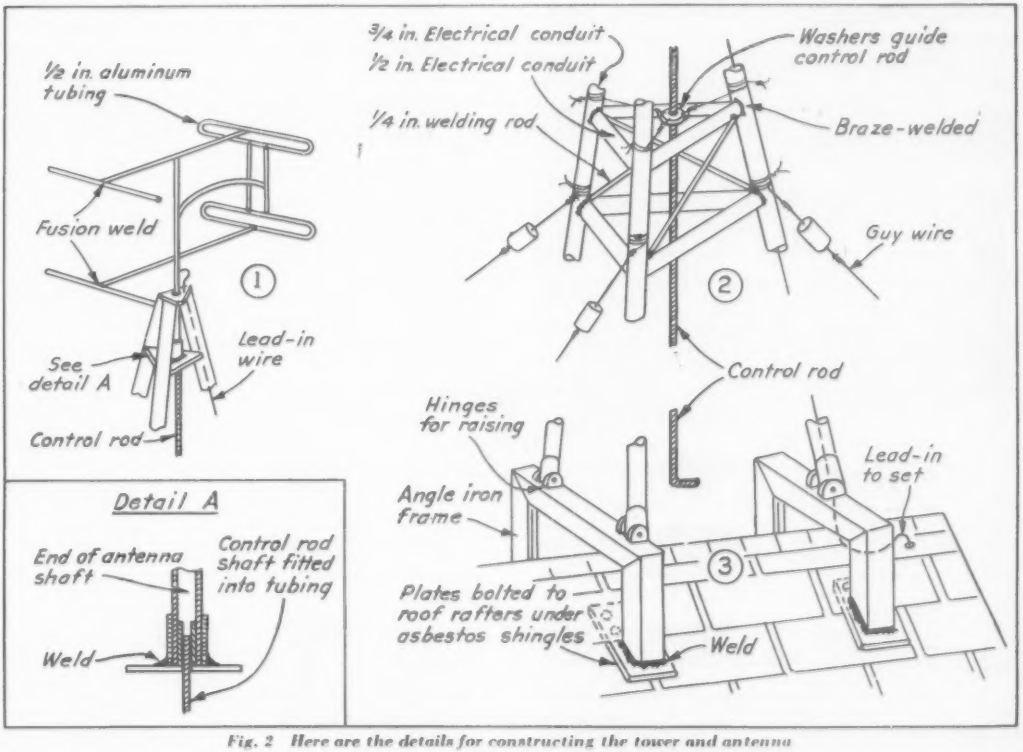


Fig. 2 Here are the details for constructing the tower and antenna

be rotated to pick up stations more clearly. This is done by means of a steel rod which is fastened to the base of the antenna and goes down to the roof. Since only two stations can be obtained in this location, the antenna is rotated by hand from the roof. In locations where more stations can be picked up, the antenna can be rotated by means of a small motor. The motor can easily be mounted on the tower, roof, or even inside the house.

Coaxial cable lead-in from the antenna runs down inside one of the legs through the roof to the set.

How Good Are Your Welds?

by R. L. Fuller

WHAT is the best way to test your welds? When you make a welded repair you want to be sure that the repaired part will give good service. Your customer also wants to know that the part is going to last.

Use the best welding equipment, the best welding rod and flux you can buy and correct welding procedures and generally you can be sure your welds are strong.

The best test for welds is to watch carefully while you are welding. For example, on your braze-welding jobs you know that strong welds depend upon proper tinning. When you can see that you are not getting good tinning, you know something is wrong. Maybe all the grease, rust, and dirt was not removed, or the metal may be too hot or too cold. Unless you correct the fault and get good tinning, you can be sure the weld will be weak. For fusion welding you know that the part must be molten when you add molten weld metal. If you do not get good fusion between the welding rod metal and the original metal, all the way to the base of the weld, it is sure to be weak.

You can test new welding operators the same way. Just watch the welding in operation and you can tell whether or not there is good tinning or fusion. After a weld has been completed you can learn something about it by studying the appearance. Of course, this does not mean that you can tell the quality of the weld by its appearance alone.

Smooth, even ripples are a good indication that you had the weld metal under control. The correct contour of the weld—a gentle slope from the center of the edge—is good evidence that the weld is sound. There should not be too much reinforcement. A maximum height of $^1/_8$ in. above the surface of the plate and a minimum of $^1/_{16}$ in. usually is about right, depending a little on the thickness of the metal. On some welded parts heavy reinforcement may actually weaken the weld. Besides, you waste welding rod, oxygen and acetylene.

Lack of penetration is a fault that usually can be detected easily. It is caused when there is not enough spacing between the parts or when the bevel was not made properly. On bronze welds it means that you did not get good tinning before you began to build up the weld. A single vee-weld should show penetration on the bottom in the form of a small bead. Too much penetration, in the form of icicles is almost as bad as the lack of penetration. It shows that the weld was overheated and therefore probably had been oxidized and weakened. Undercutting is another fault. It means that parts of the weld metal are below the surface of the parts that were welded. This is a serious defect because it greatly reduces the strength of the weld.

For those jobs which are covered by codes, standards or regulations of various governing bodies, extensive testing may be required, and should be followed exactly. For general maintenance and noncode work the foregoing instructions are a good guide.

R. L. Fuller is with The Linde Air Products, New Orleans, Pa.

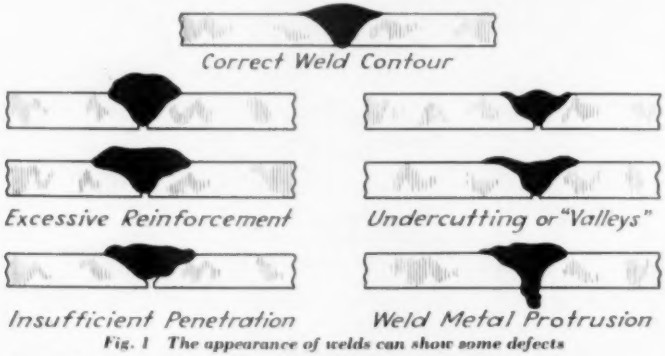
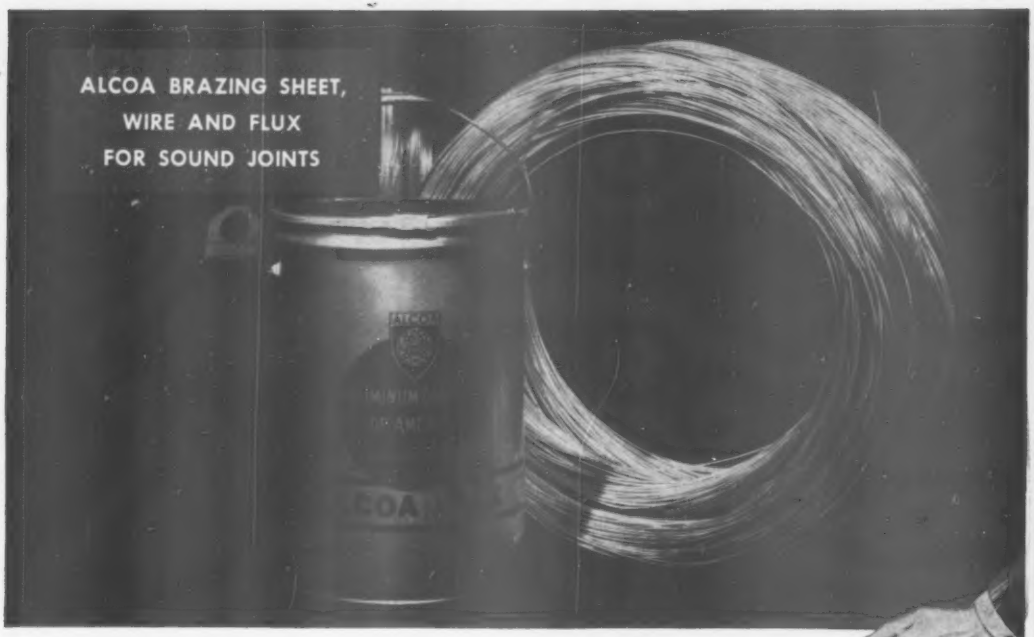


Fig. 1 The appearance of welds can show some defects

Notice that the correct weld slopes gently from the center to the sides



COMPLETE SUPPLIES FOR WELDING AND BRAZING ALUMINUM

Near as your phone!

In the listing below, you'll find an Alcoa Distributor practically in your own back yard. He's a good man to know . . . for he carries the world's best stock of flux, rod, electrodes, solder, brazing sheet and wire. Results are predictable with Alcoa supplies because they're made by the men who know the metal best.

If there is no Alcoa Distributor near you, write ALUMINUM COMPANY OF AMERICA, 1944J Gulf Building, Pittsburgh 19, Pennsylvania.

ALCOA DISTRIBUTORS NATIONWIDE:

Atlanta, Georgia
- J. M. Tull Metal & Supply Co., Inc.

Baltimore, Maryland
- Whitehead Metal Products Co., Inc.

Boston (Cambridge), Massachusetts
- Whitehead Metal Products Co., Inc.

Buffalo, New York
- Bruce-Mueller-Huntley, Inc.
- Whitehead Metal Products Co., Inc.

Charlotte, North Carolina
- Edgcomb Steel Company

Chicago, Illinois
- Central Steel & Wire Company
- Steel Sales Corporation

Cincinnati, Ohio
- Williams & Company, Inc.

Cleveland, Ohio
- Williams & Company, Inc.

Columbus, Ohio
- Williams & Company, Inc.

Dallas, Texas
- Metal Goods Corporation

Detroit, Michigan
- Steel Sales Corporation

Houston, Texas
- Metal Goods Corporation

Kansas City, North, Missouri
- Metal Goods Corporation

Los Angeles, California
- Ducommun Metals and Supply Co.
- Pacific Metals Company, Ltd.

Milford, Conn.
- Edgcomb Steel of New England, Inc.

Newark, New Jersey
- Whitehead Metal Products Co., Inc.

New Orleans, Louisiana
- Metal Goods Corporation

New York, New York
- Whitehead Metal Products Co., Inc.

Philadelphia, Pennsylvania
- Edgcomb Steel Company
- Whitehead Metal Products Co., Inc.

Pittsburgh, Pennsylvania
- Williams & Company, Inc.

Portland, Oregon
- Pacific Metal Company

Rochester, New York
- Bruce-Mueller-Huntley, Inc.

San Francisco, California
- Pacific Metals Company, Ltd.

Seattle, Washington
- Pacific Metal Company

St. Louis, Missouri
- Metal Goods Corporation

Syracuse, New York
- Bruce-Mueller-Huntley, Inc.
- Whitehead Metal Products Co., Inc.

Toledo, Ohio
- Williams & Company, Inc.

Tulsa, Oklahoma
- Metal Goods Corporation

the AMERICAN WELDING SOCIETY

activities • related events

1950-51 Officers, A.W.S.

The following candidates proposed by the 1949-50 Nominating Committee in accordance with Article XII, Section 7, of the By-Laws: were endorsed by the membership through a letter ballot and have been declared elected.

For President: H. W. Pierce, Asst. to President, New York Shipbuilding Corp., Camden, N. J.

For First Vice-President: C. H. Jennings, Engineering Manager, Welding Dept., Westinghouse Electric Corp., Box 2025, Buffalo 5, N. Y.

For Second Vice-President: F. L. Plummer, Director of Engineering, Hammond Iron Works, Box 629, Warren, Pa.

For Treasurer: R. S. Donald, Sales Engineer, 50 Church St., New York 7, N. Y.

For Directors at Large: La Motte Grover, Structural Welding Engr., Technical Sales Div., Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.; H. E. Rockefeller, Mgr., Process Development Dept., The Linde Air Products Co., 30 E. 42nd St., New York 17, N. Y.; J. R. Stitt, Research & Welding Engr., The R . C. Mahon Co., 8650 Mt. Elliott Ave., Detroit 11, Mich., and C. B. Voldrich, Welding Engineer, Battelle Memorial Institute, 505 King Ave., Columbus 1, Ohio.

Following are the candidates proposed for District Vice-Presidents and District Representatives on the 1950-51 National Nominating Committee by the District Nominating Committees in accordance with Article VI, Section 6, of the By-Laws. Only members in Districts Nos. 2, 4 and 6 are permitted to vote for District Vice-President of their District. Members of each District vote for their District Representatives on the 1950-51 National Nominating Committee:

For District Vice-Presidents: District No. 2 (Mid-Eastern)—A. G. Bissell, Principal Engr., Bureau of Ships, Navy Dept., Code 692, Washington 25, D. C.; District No. 4 (Central)—T. J. Crawford, Consulting Engineer, 3726 Kipling Ave., Berkley, Mich. and District No. 6 (Mid-Southern)—A. E. Wisler, Engineer, Hughes Tool Co., 300 Hughes, Houston 11, Tex.

For District Representatives on National Nominating Committee: District No. 1 (New York and New England)—C. E. Jackson, Res. Metallurgist, Union Carbide & Carbon Res. Labs., 4625 Royal Ave., Niagara Falls, N. Y.; District No. 2 (Mid-Eastern)—Louis Ames, Technical Sales Representative, Air Reduction Co., Philadelphia, Pa.; District No. 3 (Southern)—D. H. Curry, Welding Engineer, Chicago Bridge & Iron Co., Birmingham 1, Ala.; District No. 4 (Central)—J. R. Stitt, The R. C. Mahon Co., 8650 Mt. Elliott Ave., Detroit 11, Mich.; District No. 5 (Mid-Western)—W. G. Fassnacht, Asst. Chief Metallurgist, Bendix Products Div., Bendix Aviation Corp., South Bend, Ind.; District No. 6 (Mid-Southern)—A. K. Pandjiris, Pres., The Pandjiris Weldment Co., St. Louis, Mo. and District No. 7 (Western)—Charles L. Haynes, Asst. Supt., C. F. Braun & Co., Alhambra, Calif.

District Changes

As of the SOCIETY's fiscal year starting Sept. 1, 1950, there is effected, by approval and action of the Board of Directors, as well as agreement of the Sections involved, a change in Districts 1 and 2 Sections, namely, the New York and New Jersey Sections.

These two Sections have in the past been affiliated with District 1, known as the New York and New England District. As of Sept. 1, 1950 and thereafter until further notice, the New York and New Jersey Sections shall be affiliated with District 2, the Mid-Eastern District.

The proposal to make this change was submitted on the occasion of the meeting of the Section Advisory Committee in Philadelphia during the Annual Meeting in 1948. It was observed that geographic locations of the New York and New Jersey Sections, transportation facilities, etc., indicated a better working pattern if the two Sections named were contained within the same District group as Philadelphia, Baltimore, Washington and other nearby Sections. The proposal of the Section Advisory Committee was submitted to each of the current District Officers, as well as to the current Section Officers. Each Section voted thereon and the decisions in all instances were favorable to the change. The recommendations were presented to the National Board of Directors and such received their approval.

All Sections in Districts 1 and 2 have been accordingly officially notified by letter from National Headquarters and hereafter the records of the SOCIETY shall indicate the New York and New Jersey Sections' affiliation with the Mid-Eastern District,—District 2.

Record Breaking Attendance at 1950 A.S.T.M. Annual Meeting

The 53rd Annual Meeting of the American Society for Testing Materials held in Atlantic City June 26th to 30th was as usual featured by a large number of technical papers and reports given in the 23 formal technical sessions, and throughout the week there were upward of 500 meetings of the A.S.T.M. technical committees. Another interesting feature was the biennial Exhibit of Testing Apparatus and Related Equipment together with the Photographic Exhibit which featured prints, photomicrographs and electron micrographs on engineering materials.

The registered attendance—2134—is a new high, exceeding the previous figure of 2064 for the 1944 Annual Meeting in New York City. Many other technical people were at the meeting, visiting the exhibits or attending the technical sessions.

Recommendations from technical committees resulted in 68 new specifications and tests, with revisions in some 200 existing standards and tentatives. All of these will be published separately and also in the 1950 Supplement to the *1949 Book of A.S.T.M. Standards*. The total number of A.S.T.M. Standards is now about 1675.

Journal Questionnaire

On Jan. 23, 1950, with the approval of the Board of Directors, a Questionnaire was sent to the entire membership (about 7200) to ascertain reader interest in various sections of the JOURNAL.

On April 1st the returns were declared officially closed and the task of analyzing the 726 replies was undertaken. Each questionnaire had 115 possible votes and 11 places for comments. These votes were further divided in 16 job categories.

The comments occupied 155 typewritten pages and the votes reduced to percentage basis occupied 10 additional pages.

Briefly the results of this questionnaire led the WELDING JOURNAL Committee to the following basic conclusions:

1. The JOURNAL as a whole is helpful to 95% of the responding members. Three per cent of the responding members had difficulty in locating the Contents page and therefore the WELDING JOURNAL Committee recommends to the Board that the cover be redesigned to include the feature articles and the page location of the Contents page and Advertisers Index.

2. The Engineering and Technical Articles are acceptable to 88% of the responding members and should not be changed.

3. The Practical Welder and Designer Section is liked by 78% of the responding members and should be continued in about the same proportion.

4. The Principal Departments in the

In every major plant welding personnel state:

"I read Welding Journal"

Survey after survey shows that Welding Journal is read by approximately 30,000 engineers, executives, designers, draftsmen, supervisors, technicians and practical welders every month . . . reaching the "behind the scenes" purchasing power of the welding industry at the lowest unit cost. Why do these men read the Welding Journal? Because:

1. **Welding Journal** is the official organ of the American Welding Society and the Welding Research Council.

2. **Welding Journal** contains more than 2½ times the editorial material on welding than any other magazine in the world.

3. **Welding Journal** each year gives its readers the results of more than a million dollars' worth of research.

4. **Welding Journal** contains news articles and regular feature sections of direct interest to the practical welder, as well as welding engineers, engineers who are interested in welding, and designers.

5. **Welding Journal's** "News of Industry", "New Products", and "New Literature" sections are the "Bible" of the industry.

SO REMEMBER — WELDING JOURNAL gives you more for your advertising dollar than any other welding publication in the world!

WELDING JOURNAL

News Section are well received. Examples:

	%
Like Society and Related Activities	71
Like News of the Industry	88
Like New Literature	85
Like New Products	90
Like Section Activities	60

5. The Research Supplement should be continued, 50% voted against separation and only 22% voted in favor of separation.

6. The Advertising is read by 88% of the responding members and found helpful by 74% of them with 49% making actual purchases as a result of ads in the JOURNAL. These comments will form the basis of a new advertising brochure.

7. The $50 U. S. Saving Bond was awarded to Ludwig Adams, Research Engineer, Pittsburgh-Des Moines Steel Co., as sending in the most helpful questionnaire. Honorable mention goes to: C. M. Clogston, Chief Welding Engineer, Northern Pump Co.; Charles Kandel, President, Craftsweld Equipment Corp., and K. V. King, Engineer, Standard Oil Co. of California.

There follows a detailed analysis of the replies on a percentage basis:

I. The JOURNAL as a whole:

Do you like the JOURNAL'S appearance?	Yes 98	No 1
Is the type easy to read?	97	1
Do the Titles and heading help you decide what to read?	92	4
Are enough pictures and diagrams used?	79	16
Do you like the "Contents" page?	87	4
Is the JOURNAL helpful to you?	95	2

II. Engineering and Technical articles:

A. Are enough subjects covered in each issue?
75 Enough. 15 Not enough. 6 Too many.
Are these articles easy to understand?
9 Always. 74 Usually. 14 Sometimes. 0 Never.
Should articles be:
24 Long and detailed.
56 Short as possible.

B. How about language? Is it:
Too technical 8. Too simple and indefinite 2. Generally all right 88.
How often do you find articles of special interest to you?
60 in every issue. 31 about every 3 months. 4 Once or twice a year. 1 Seldom if ever.

III. Practical Welder and Designer

A. Do you like this section?
78 Yes. 8 No
Do you find the articles useful?
66 Yes. 3 No. 17 Not useful in my line of work.

B. What kinds of articles do you like?
Articles on Repairs? 40
Articles on How to do specific jobs? 56
Articles on How to weld specific metals? 69
Articles on Jigs, fixtures or tools? 48
Articles on Practical design? 58
Articles on hard surfacing? 35
Articles on Making new devices? 43

C. Are these articles easy to understand?
84 Yes. 2 No.

D. Are they adequately illustrated?
74 Yes. 11 No.

IV. News Items

	Like	Don't Like	Just Not Interested
Society and related activities	71	1	13
News of the industry	88	1	4
Personnel news	57	3	27
New literature	85	1	
New products	90	1	35
Employment Service Bulletin	44	1	37
New patents	68	2	20
Section Activities	60	2	25
New Members	52	3	28

V. Research Supplement

A. Please check statement that most nearly expresses your ideas *about the Research Supplement only.*
1. Often find helpful ideas in this section. 35
2. Think this is the most important and helpful part of the JOURNAL. 25
3. Never read the Research Supplement. 4
4. Occasionally contains useful articles. 24
5. Find this section very interesting and helpful. 29
6. Never find anything in it helpful in my work. 4

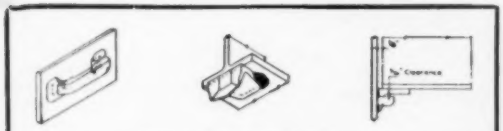
B. I think that articles in the Research Section are usually

	Yes	No	No Opinion
Timely and useful	50	2	16
Good to have on file	73	2	5
Too short	4	34	13
Easy to read	42	15	9
Easy to understand	36	13	8
Interesting	54	4	7
Too long	17	23	13
Don't apply to my work	12	22	8
Could be simplified	30	13	14

C. Should the Research Supplement be published separately and sold to those interested?
22 Yes. 50 No. 15 No Opinion.

VI. Advertising

	Yes	No
Do you read the ads in the Journal?	88	6
Do you find them helpful?	74	9



WELDING CONNECTORS
Saxe System Welded Connection Units
for welded assembly

Saxe Units place in position and securely hold together structural parts to be welded.

As used in many welded structures they *eliminate all hole punching* producing an economical, rigid, safe and quickly erected structural frame.

"Write for 58 pg. Manual containing full engineering design information for welded structures."

J. H. Williams & Company
Buffalo 7, New York

G. D. Peters Company
Montreal 2, Canada
Canadian Representative

SPECIALIZING IN "BETTER-BUILT"
WELDING & SAFETY EQUIPMENT
FOR OVER 25 YEARS

There is a DOCKSON distributor near you. Name on request.

Write for our complete Welding and Safety catalogs.

Dockson CORPORATION
3939 WABASH • DETROIT 8, MICH.

This new WELDING DESIGN MANUAL

EUTECTIC

yours . . . FREE for the asking!

To assist you in your re-tooling problems . . . or to help you analyze your present welding methods so that you may enjoy maximum speed, efficiency, and economy in many of YOUR production problems, EUTECTIC offers — FREE of charge and without obligation — this new, packed-full-of-information book!

Over 40 pages of helpful data covering basic and advanced welding techniques and designs used in fabricating and assembly. Profusely illustrated with scores of application drawings, weld diagrams, how-to-do-it sketches, etc. In addition, you will find page after page of tables containing latest information on melting temperatures, tensile strengths, corrosion factors, nomenclature, alloy recommendations, etc. Convenient digest size.

This just-off-the-press book is "must" reading for anyone engaged in defense production and design, and will certainly be time profitably spent for any production man.

THIS PARTIAL LIST OF CONTENTS SHOWS THE WEALTH OF VALUABLE INFORMATION IN THIS HANDY MANUAL— *yours FREE*

Definition of Terms • Technology • Temperatures of application • Joining Methods: Torch Joining; Arc Joining; Induction Joining; Furnace Joining; Inert Arc Joining • Recommendations of Types of Joint and Heating Methods • Design Information: Square Butt Joint; Lap Joint; Flange Joint; Beveled Butt Joint; Fillet Weld; Overlay • Fluxing and Removal of Flux • Inspection and Control • Heat-treating of Welded Parts, and Welding of Heat-treated Parts.

—AND SCORES MORE . . . INCLUDING sketches and data on welding alloys for use with: cast iron, all steels, stainless steel, copper, brass, bronze, nickel and its alloys, magnesium, aluminum, hard and machinable overlays, etc., etc., etc!

Re-Tooling Now? . . . or Later??

Some firms have already started their re-tooling operations, some are still in the planning stage. Regardless of which stage YOU are in, it will pay you to start checking up NOW on the latest welding techniques and on the many ways you can speed productive output while you cut production costs through a revision of *your* welding designs and techniques. *Send for your FREE copy of this helpful manual TODAY.*

SEE HOW 10 years of EUTECTIC'S continuing welding research have evolved radically new metal joining techniques and designs.

WHY over 67,000 plants throughout America specify genuine "EUTECTIC" for all their welding alloy needs.

WHICH of your present designs can be altered to take advantage of these new production methods.

CLIP AND MAIL THIS COUPON TODAY

EUTECTIC WELDING ALLOYS CORPORATION
40 Worth Street **New York 13, N. Y.**

EUTECTIC WELDING ALLOYS CORPORATION
40 Worth Street, New York 13, N. Y.

This new manual of yours sounds like a very helpful book. Send me a FREE copy with the understanding that there will be no cost or obligation now or later.

Signed _____

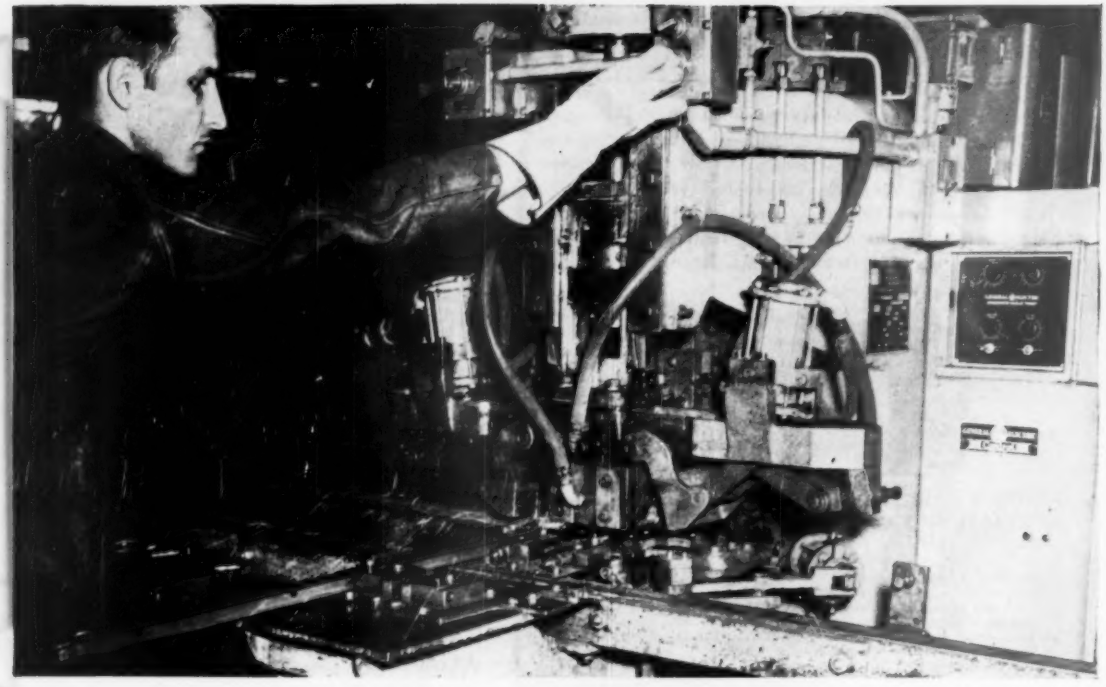
Firm _____

Address _____ *Zone* _____

City _____ *State* _____

G-E NONSYNCHRONOUS

Better than ever



All the control you need—including accessories—is contained in the modern attractive cabinet. Combines all the advantages of standard components with the specialized details and refinements required for your work. Nonsynchronous control is commonly required for welding standard steels such as are used for automobile bodies, stoves, furnaces, refrigerators, motors, etc. Here it is used for welding hinges to a steel window frame at Copco Steel and Engineering Company, Detroit, Michigan.

GENERAL ELECTRIC

CONTROL for resistance welding

at lower Price!

G-E nonsynchronous control for resistance welders has been simplified, price reduced about 8 per cent.

Only *two* relays as compared to the previous *six* cut sequence time, mean faster operation. There is less wear, therefore, *less maintenance required*. The entire unit is more compact—*takes less space*. *Timing is now controlled electronically*.

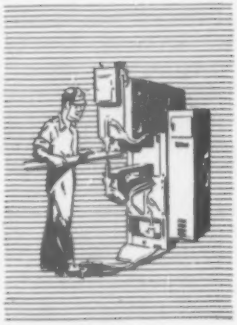
General Electric development engineering and improved manufacturing methods have again resulted in lower prices, better operating methods for the user of resistance welders. This is an example of the continued efforts at General Electric to give you more precise control of this process. When you have resistance welding control problems, contact the nearest G-E sales engineer. You'll be sure of unbiased answers. You'll get the *right* control for the job. And when you order control—specify General Electric.

SEE "This is Resistance Welding" . . .

General Electric's More Power to America four-color, sound motion picture covering every phase of this manufacturing process. Contains tips for improved production for operators of machines, design engineers, and supervisors. Contact your Resistance Welder manufacturer, Power Supplier, or the nearest G-E office.

EASY TO INSTALL—
compact, factory assembled unit may be mounted on the side of the machine, floor, nearby wall, or balcony as space permits.

EASY TO SERVICE—
entire side of cabinet is a hinged door which opens to provide quick, easy servicing of circuit components, power tubes, and water system.



EASY TO OPERATE—
control station usually faces operator, but may be installed at the side of unit when mounted on machine, or may be separate from unit if remote control is desired.

SEND COUPON TODAY!

Apparatus Dept.,
General Electric Co., Sec. A645-51
Schenectady, New York

Please send me supplement No. 1 Bulletin GEA-4726 on Nonsynchroneous Welding Control.....

I would like a showing of "This is Resistance Welding".....

NAME.....

ADDRESS.....

.....

	Yes	No
Have you ever bought products as a result of reading JOURNAL ads?	49	32
Have you ever investigated a new process you saw in a JOURNAL ad?	68	20

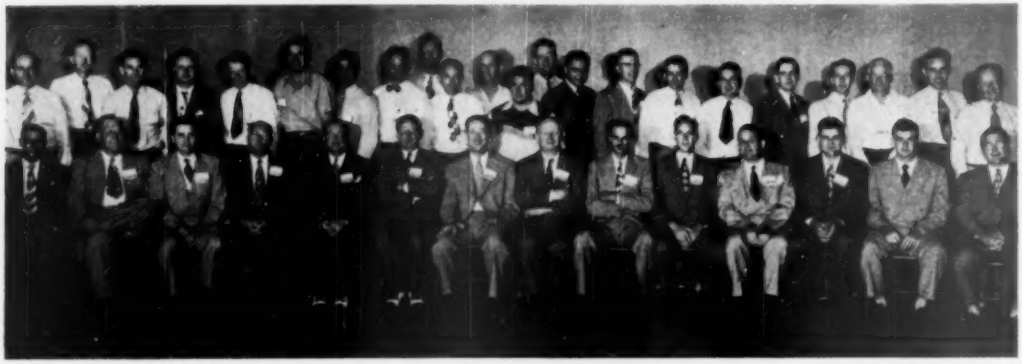
Mid-Southern District Meeting

A meeting of the Mid-Southern District Officers was held in Tulsa, Okla. on July 15th. There were a total of 38 individuals present, representing the Dallas, Denver, Houston, Kansas City, Oklahoma City, St. Louis, Tulsa and Wichita Sections. Present also were O. B. J. Fraser, National President of the SOCIETY; Howard N. Simms, National Director; R. L. Townsend, District Vice-President and A. E. Wisler, District Vice-President elect.

Each of the Sections outlined the successes and failures which they had had in the past year and exchanged suggestions as to how improvements could be made in the operations for the coming year. Several of the Sections had special membership plans. Others were concentrating on special program features. All stressed the need of giving particular attention to the retention of old members and the improvement of meetings.

Safety Congress

The 38th National Safety Congress and Exposition, will be held Oct. 16–20, 1950 in Chicago, Ill. Sessions on industrial safety scheduled for Stevens, Congress and Morrison hotels; traffic safety sessions at Congress Hotel; commercial vehicle, farm and home safety sessions at La Salle Hotel and school sessions at Morrison Hotel. For further information write R. L. Forney, general secretary, National Safety Council, 425 N. Michigan Ave., Chicago 11, Ill.



Delegates to the Mid-Southern District A.W.S. Meeting

BECKER

Twenty-eight pages of easily found information, complete with factory model numbers, replacement brush numbers, scaled illustrations of brushes listed, and all other necessary data. Here is a regular "Encyclopedia" of Brush information covering all types and makes of welding equipment.

SEND FOR YOUR FREE COPY NOW!

BECKER BROTHERS CARBON CO.

3450 SOUTH 52nd AVE. CICERO 50, ILL.

CARBON

MOLDED CARBON and GRAPHITE *Specialties*

Seldom can any material surpass carbon and graphite for practical solutions to problems involving friction, high temperatures, corrosion, shaft sealing, and arcing

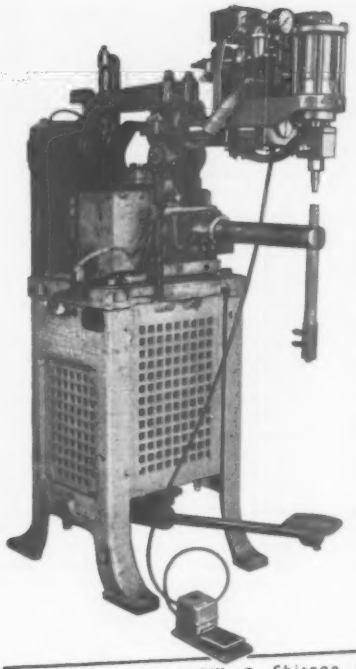
Let This Booklet Help You!

Write on company stationery for your copy of the Stackpole Carbon Specialties Book 40. Besides describing dozens of Stackpole items, it contains interesting evidence of the amazing versatility of carbon and graphite in modern design and engineering.

STACKPOLE

STACKPOLE CARBON COMPANY

St. Marys, Penna.



Convert Rocker Arm Spot Welders to Fast Air Pressure Control

with WELD-AIR-MATIC!

Compact • Low Cost • Self Contained
Eliminates old-fashioned foot control

Step up spot welding capacity now with the new Weld-Air-Matic Control Unit. One simple, easy installation and your present foot-control type welders can attain a new peak of efficiency on continuous, full-load production schedules. With machine after machine, Weld-Air-Matic units are achieving a high record of 10,000 welds per hour on continuous, 8 to 10 hour daily schedules.

Clamps to Upper Horn of Welder

Weld-Air-Matic is one integral installation unit, complete with all accessories mounted on a strong, aluminum alloy casting. It provides a feather-touch electric foot switch to control air pressures and energize a coil on a four-way operating valve.

Take advantage now of up-to-date Weld-Air-Matic air pressure operation. Convert your present equipment. Achieve easier operation, greater speed and accuracy in welding without the cost of machine replacement.

SWITCH TO SPEED WELDING with WELD-AIR-MATIC

- Three standard sizes available.
- Operates on reduced air pressure of 15 to 50 lbs.
- Maximum stroke, 1½" on size 1 welder, 2" on size 2, 2½" on size 3.
- Used with any standard Weld Timer.
- Requires minimum of 4 cubic feet air supply per minute—minimum 80 lbs. line pressure.

Write today

for complete details—learn all the facts on the savings possible NOW with Weld-Air-Matic!

Visit the METAL SHOW • Chicago • Oct. 23 to 27 and see our new SHOW ROOM at 32 South Clinton St.

ROBT. W. HOFFMAN COMPANY, Inc.

36 South Clinton Street

Chicago 6, Illinois

Recommended Practices for Metallizing

Recommended Practices for Metallizing: Part IA Metallizing Shafts or Similar Objects and Part II Metallizing—Safety Recommendations, consisting of 22 pages, illus., and published by AMERICAN WELDING SOCIETY.

The first in a series of metallizing standards to be issued by the AMERICAN WELDING SOCIETY has just been published. This standard, in two parts, covers all methods of surface preparation, metal-spraying procedures and finishing of sprayed metal shafts or similar objects and safety recommendations to be followed in metallizing operations.

The preparation of this standard was prompted by the demands of industry for authoritative information which could be used as a guide in the increased applications of metallizing today. This first standard of the series makes it possible to select the most suitable procedures for different types of application. Tables provide information on the depth of undercut for different classes of services and different sizes of shaft; weights and other properties of wire used for spraying; and suggested machine settings for the electric bond method of surface preparation. Also included is a formula for computing the rate of spraying.

Copies may be obtained at 75 cents each from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

The usual discounts of 25% to A and B members and 15% to C members will apply.

Resistance Welding Symposium

Are you making resistance welded products? Do you spot weld aluminum or magnesium? Do you projection weld copper alloys? Do you resistance weld nickel and its alloys, or magnesium or mild steel or stainless steel? Do you spot or seam weld galvanized steel or some other type of coated steel?

If your answer is yes to any of these questions—in short, if you have any interest in resistance welding you will want to accept this invitation to attend the Panel Discussion on Resistance Welding at the A.W.S. Annual Meeting sponsored by the A.W.S. Resistance Welding Committee.

This will be a session of *discussion*, not long papers. You will hear about the other fellow's problems and how he solved them. You will be given an opportunity to discuss your own problems as well.

Each subject will be opened with a few brief remarks by a man well qualified in that subject who will then conduct the discussion. High-speed movies will be shown. The use of the *Recommended Practices for Resistance Welding* will be discussed and suggestions considered for amplifying them to better meet your needs.

Be sure to note the date and place—*Monday, October 23, 1:30 P.M.*, Bal Tabarin Room, Hotel Sherman. Consult the full Annual Meeting Program printed elsewhere in this issue for further details.

Applied Welding Engineering

The question "What is Welding Engineering?" has aroused considerable discussion recently. There are many concepts and opinions concerning the inter-relationship between the materials, design, workmanship (manufacturing) and inspection used in producing a product or structure which will satisfy the service conditions for which it is intended.

To provide for an interchange of ideas and a general discussion of the subject, the Technical Acitivities Committee of the SOCIETY is sponsoring a session on "Applied Welding Engineering" at the A.W.S. Annual Meeting on Tuesday, Oct. 24, at 8:00 P.M. in the Bal Tabarin Room of the Hotel Sherman.

Following the presentation of a series of short papers, illustrated with slides and practical examples, presented by nationally recognized welding authorities there will be a general discussion of the subject from the floor. Further details of the program will be found in the full Annual Meeting Program elsewhere in this issue of the JOURNAL.

The time for this session has been selected so as not to conflict with any other Annual Meeting activities. Be sure to make a note of this session.—You will surely want to attend!

NEWS OF THE INDUSTRY

Bausch & Lomb Named Tuf-Cote Distributor

A preparation for coating safety lenses to make them more resistant to welding splatter and emery pitting is now available to purchasers of Bausch & Lomb ophthalmic lenses.

The preparation, known as Tuf-Cote, has been made available through an arrangement effected by Bausch & Lomb and the Wallace Optical Co., Inc., of Detroit.

Frederick J. Koeth, manager of Bausch & Lomb's Protective Eyewear Division, announces that lenses treated with Tuf-Cote will be supplied by all Bausch & Lomb sales and service divisions and affiliated offices.

Tuf-Cote's effectiveness is d rived from its resilience, which cushions the impact of particles striking against lens surfaces and keeps them free from pits and scratches resulting from these and similar causes for a substantially longer period than is the case with untreated lenses.

The process involves the patented application of a crystal-clear solution. Both surfaces may be treated if desired. The coating, Koeth stated, produces no distortion, does not discolor or peel off, and permits the same degree of vision as is afforded by untreated lenses, thus preserving surface quality for much longer periods of time and contributing to economy and safety. Lenses can be recoated indefinitely so long as their surfaces are undamaged.

A prescription lens of any curvature, Koeth said—from plano lenses up to corrections of plus or minus 15 diopters, with the single exception of Ultex K, segment side—can be treated successfully. The process is applied largely to safety glasses but may be used in the coating of conventional dresswear lenses as well.

Method of Compiling Injury Rates

Since 1937, the American Standard Method of Compiling Industrial Injury Rates, Z16.1, has been the recognized guide for all industries in compiling industrial injury rates. This code was last revised in 1945. Since then, it has attracted more and more attention throughout industry.

Sectional Committee Z16 which is responsible for the drafting and revision of this Code has found, as the use of the code increased, that separate industries have different interpretations of the code requirements. Since these differences in interpretation result in lack of uniformity and comparability in injury rates, the committee feels every effort should be made to determine why these differences exist and how best to resolve them.

Sectional Committee Z16 is interested in obtaining information as to the methods used in the welding industry in reporting injuries and compiling injury rates. They are especially desirous of knowing whether the methods used conform to American Standard Z16.1 and if not why deviations from this standard are deemed necessary. Questions or suggestions concerning the interpretation of any of the requirements of Code Z16.1 will be most welcome.

Please send your information, suggestions or questions to H. B. Daffus, Chairman A.S.A. Sectional Committee Z16, c/o Westinghouse Electric Corp., P. O. Box 1017, Pittsburgh 30, Pa. If the compiling of injury rates is handled by a separate safety department in your company, will you call this matter to its attention.

Milburn Returns to Welding Field

One of the oldest brand names in the gas-welding industry is now actively on the market again as a result of the incorporation of Alexander Milburn, Inc., 1231-1245 Ridgely St., Baltimore 30, Md. The new company will manufacture and market the famous Milburn line of oxy-acetylene cutting and welding apparatus, regulators for oxygen, acetylene and other gases, accessories and supplies and portable carbide lamps. The Milburn name has been known throughout the gas-welding industry since 1907.

Since 1945, Milburn equipment has been marketed by The Black Mfg. Co., Parkton, Md.

Arthur B. Sonneborn Co. Moves Flint Office

Arthur B. Sonneborn Co., Michigan and Northwestern Ohio representatives of National Electric Welding Machines Co. of Bay City, Mich., announces the removal of its Flint, Mich. offices to 314 Paterson Bldg. Flint 3, Mich. Other offices of the company will remain at 631 Fisher Bldg., Detroit; 1322 Grand Rapids National Bank Building, Grand Rapids; and Room 206, 1118 Madison Ave., Toledo, Ohio.

Skilled Construction Men Needed

Skilled construction men over the age of 25 can still enlist in the Naval Reserve as Seabees and receive petty officer ratings equal to their civilian experience, the Navy has announced.

By joining the Seabee Volunteer Reserve, older men in the construction trades not only will retain their rating when and if they are called to active duty, but they will also have reasonable assurance that they will be assigned to Naval Construction Battalions for high-speed building and defense of overseas bases.

The same opportunity to join this standby Reserve no longer is available to men in the 19 to 25 age group because they have become subject to induction under the Selective Service Extension Act of 1950.

Approximately 70,000 additional experienced construction men are wanted in the Seabee Volunteer Reserve. This is considered the minimum number needed for a nucleous to develop the construction speed that would be required of the Seabees in case of full-scale war.

The seven Seabee ratings open cover some 60 different civilian construction skills. These ratings are: builder, mechanic, steelworker, utilities man, construction electrician, driver and surveyor. Volunteers will be placed on inactive duty, with no drills or required meetings. They may be called to active duty when required.

Enlistment in the Volunteer Reserve is limited to men who have reached their 26th birthday but not their 45th. The upper age limit is extended in case of veterans to the same number of years beyond age 44 as their previous military service. If this previous service has been with the naval service, volunteers will be accepted up to age 50½ years, plus the number of years of naval service.

Depending on the kind and amount of civilian experience, skilled construction men can expect to be rated at some point in the scale between Chief Petty Officer, with minimum active duty base pay of $198.45 per month, to Third Class Petty Officer, with a minimum of $117.60. Additional pay is given for dependents and for years of previous service.

Those desiring to volunteer should get in touch with the Commanding Officer of any Organized Reserve Construction Battalion Company or Volunteer Construction Battion Reserve Unit. These are located in more than 300 principal cities throughout the country. Application also can be made at any Naval Recruiting Station.

Radiographic Testing Recommendations

All persons interested in radiographic testing are invited to submit criticism and comments on a new Recommended Practice for Radiographic Testing which has been developed after intensive work by the committee of the American Society for Testing Materials responsible for such work, namely Committee E-7 on Nondestructive Testing. The project is handled in Subcommittee I on Radiographic Procedures.

The proposed recommended practice is an expansion of material formerly included in the now withdrawn methods of radiographic testing E-15.

At its session during the A.S.T.M. Annual Meeting in June, Committee E-7 voted that the new document should be distributed for criticism, and copies are now available from A.S.T.M. Headquarters at 50 cents each. The proposed Recommended Practice has been duplicated and covers 27 pages.

The subject matter of the proposed recommendations is divided as follows: Part I. Equipment and Calibration; Part II. Exposure Factors and Arrangements of Parts; Part III. Protection and Care of Films; Part IV. Processing Films and Viewing Radiographs and Part V. Records, Reports, and Identification of Accepted Material.

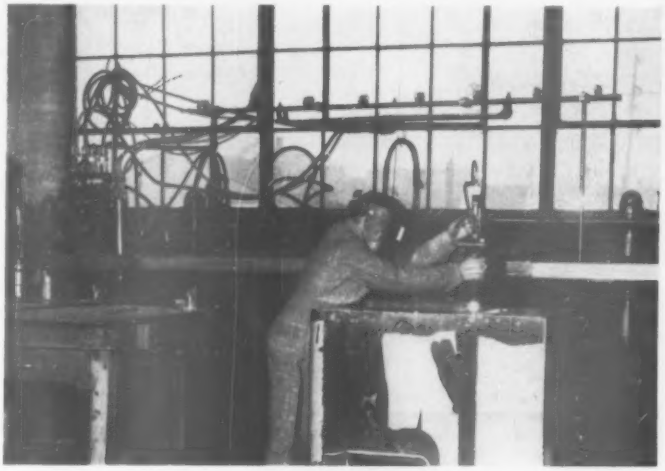
An effort has been made to include specific instructions for carrying out the various steps of the radiographic process according to the best practice but without the usual explanatory material which is found in the literature. The subcommittee recognized at the start, however, that it could easily overlook features which might be important or include unimportant material. Accordingly, it requests that readers submit constructive criticism. All persons interested in industrial radiography are urged to obtain this pamphlet by writing directly to A.S.T.M. Headquarters, 1916 Race St., Philadelphia 3, Pa. Criticisms should be addressed to the Chairman of the Subcommittee, Dr. H. E. Seeman, Research Laboratory, Eastman Kodak Co., Kodak Park, Rochester 4, N. Y. To receive consideration for the first revision, comments must be in by Oct. 16, 1950.

From Shape Cutting to Shape Welding

The versatility of the Airco 6A Oxygraph, a pantagraph-type oxyacetylene cutting machine, was thoroughly tested recently when the machine was pressed into service as a shape-welding unit.

Peters-Dalton, Inc. of Detroit, Mich., dismounted the cutting torch, replacing it with a Heliweld machine holder and proceeded to use the unit to shape-weld ends for a 16-gage, Type 304 stainless steel conveyor-type dishwasher they are now manufacturing.

Another interesting feature of this operation is the materials handling operation



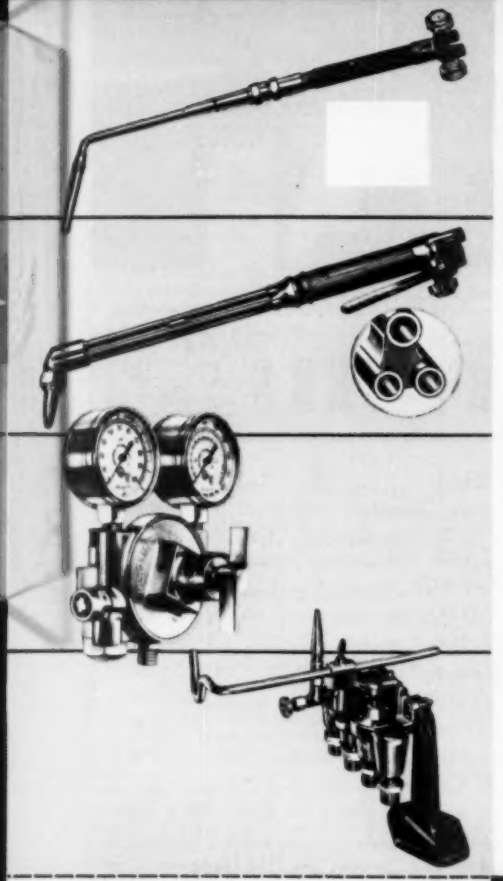
INDEX TO ADVERTISERS

Air Reduction Sales Co. ..... Outside back cover, 814 & 815
Aluminum Company of America 775
American Chain and Cable Co. 795
American Manganese Steel Division 801
Arcos Corporation 794
Bastian-Blessing Co. 799
Becker Brothers Carbon Co. 782
Bernard Welding Equipment 813
The Champion Rivet Company 802
Dockson Corporation 778
Electric-Arc, Inc. 808
Eldorado Mining & Refining Ltd. 830
Eutectic Welding Alloys Corp. 779, 798
General Electric Co. ..... 780 & 781, 818 & 819
Handy & Harman 807
Hobart Brothers Company 703
Robt. W. Hoffman Co., Inc. 783
The International Nickel Co., Inc. 791, 805, 811
Jackson Products ..... Inside back cover
Lincoln Electric Company 809
The Linde Air Products Company, Unit of Union Carbide and Carbon Corporation 707
P. R. Mallory & Co., Inc. 705
Metal & Thermit Corporation 704
National Carbide Company 800
National Cylinder Gas Co. 786
Page Steel and Wire Division 795
Reid-Avery Company, Inc. 793
Stackpole Carbon Co. 782
The Tempil® Corporation 827
Tube Turns, Inc. ..... 788 & 789
Tweco Products Company ..... Inside front cover
Union Carbide and Carbon Corp., The Linde Air Products Company, Unit 707
Victor Equipment Company 708
Westinghouse Electric Corporation 803
Worthington Pump & Machinery Corp. 817
J. H. Williams & Co. 778

YOU'LL GO FOR REGO

A NAME THAT HAS MEANT QUALITY FOR 40 YEARS

PROVE IT TO YOURSELF—TEST ANY ONE OF THESE 4 BASIC ITEMS



1 Rugged, performance-proved GX Welding Torch

Typical of REGO quality is this widely preferred Welding Torch. Stronger than steel, lighter than brass, the unique GX handle has no tubes, screws or soldered joints. Stainless steel head further guarantees long life. Four handle lengths and a broad variety of free-flow mixers and tips fit the GX to any welding job, regardless of size.

2 Dependable, gas-saving KX Cutting Torch

Thousands of industrial plants, scrap yards, railroads and shops have relied exclusively on this torch for years. Stainless steel head and triangular tube construction make the KX tough and durable. Diaphragm-type valve prevents leaks, provides sensitive control. Tip-mixing stops flash-backs. Available with lever on bottom or side, and with 75° or 90° heads.

3 Precise, balanced-action Two-Stage RegOlator

The regulator that has won fame for accurate delivery of all types of industrial gases! Its two stages combine stem-type and nozzle-type design to assure delivery of unvarying working pressures. Running back and forth from work to regulators for adjustments is eliminated. A point-by-point comparison will quickly establish the excellence of the REGO RegOlator.

4 Redesigned, improved REGO Economizer

This time-proven money-saver is even more efficient now. New 90° lever permits welding torch to hang with tip toward pilot flame. New pilot is aspirator type, providing longer and more stable flame. To relight the torch at its previous flame setting, just lift from lever hook; to extinguish, replace on hook. This is the automatic shut-off that has saved innumerable hours of welding production time.

NATIONAL CYLINDER GAS COMPANY
858 N. Michigan Ave., Chicago 11, Ill.
Rush me catalog and price list on REGO Outfits and Apparatus, for welding and cutting.

NAME_____ POSITION_____

COMPANY_____

ADDRESS_____

CITY_____ ZONE____ STATE_____

Copr. 1950, National Cylinder Gas Co.

YOU OWE IT TO THE EFFICIENCY OF YOUR SHOP TO WRITE FOR THE COMPLETE REGO CATALOG

NCG

EVERYTHING FOR WELDING

NATIONAL CYLINDER GAS COMPANY
Executive Offices: 858 North Michigan Avenue
Chicago 11, Illinois

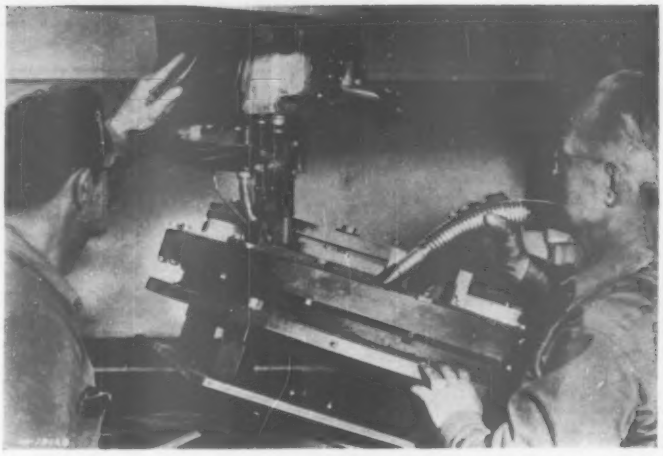
*T. M. of the B. B. Co., Chicago

involved. In order to have the washer end at the proper height for welding, it was necessary to prepare a pit into which the washer units are lowered end down. After the first end is welded, the unit is reversed and the other end is welded. Using a magnetic tracing device, the welding speed achieved is 35 in. per minute.

Automatic Welding 18–8 Stainless

To fabricate J47 turbo-jet components at high-production speeds and with uniformly good quality welds, the Solar Aircraft Co. of San Diego, Calif. has set up a production line in which automatic-hidden arc welding is used. The 18–8 stainless steel parts are welded with a standard automatic head manufactured by The Lincoln Electric Co. of Cleveland, Ohio, using an 18–8 type filler wire.

Excellent results are obtained with the welding technique worked out, involving rigidly controlled high heat inputs and rigid fixtures to maintain accurate alignment of parts. The fixture is mounted on a rotating positioner which revolves the work under the welding head.



Automatic Welding 18-8 Stainless

Swift Appoints Indianapolis Firm as Representative

The Swift Electric Welder Co., 8095 Livernois, Detroit 4, Mich. has announced the appointment of the Indianapolis Machinery & Supply Co. of 1959 South Meridan St., Indianapolis as distributors and representatives for Indiana and Southern Illinois.

Welding Course

Automatic submerged arc welding, wrinkle bending and other phases of the modern torchman's art were described and demonstrated to more than 100 short coursers at a three-day school closing at California State Polytechnic College's San Luis Obispo campus June 23rd.

Held at instance of the trade, the Cal

Unionmelt Welding of Odd-Cylindrical Shape

Girth welds on the cylindrical portion of a hot-air furnace are made on both ends at once by Unionmelt welding and use of the roll-over fixture illustrated in the photograph. Engineers at Kalamazoo Stove Co., Kalamazoo, Mich., working in conjunction with engineers of The Linde Air products Co., were able to mechanize practically the entire welding operations and thus cut handling costs and boost production.

The roll-over fixture was made by oxygen cutting two large circular plates. Cutouts were made to fit the shape of the air furnace. Braces and supports tie the two pieces together. The fixture is easy to load and unload because sections of the wheels are hinged.

Two Unionmelt welding heads are placed on stationary pedestals. The one at the right (see illustration) makes a continuous weld through the flanged-ash bottom, joining it to the shell of the furnace. The Unionmelt head at the left is adjusted at the top of the cylinder and makes an outside weld—joining the top of the furnace to the shell. The fixture is placed on motor-driven rolls and turns at the proper welding speed.

Frequently, a complex shape-welding job can be broken down into two or more simple operations. By using this fixture and breaking down the complex welds into simple straight-line and girth welds this fabricator was able to take advantage of the high-speed, high-quality features of Unionmelt welding and also to double the advantage by welding both ends of the furnace simultaneously.

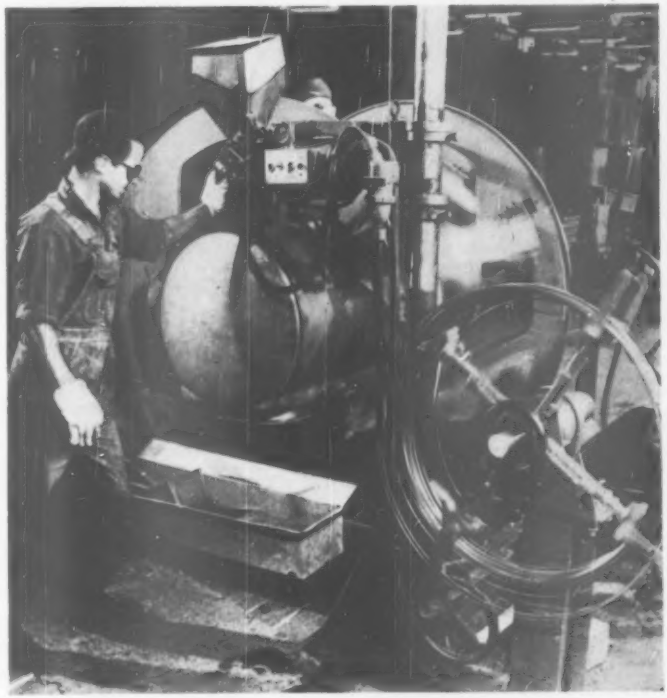


Fig. 1 Top and bottom of hot-air furnace are automatically welded simultaneously by Unionmelt welding with this roll-over fixture

Poly short course attracted welding employees, executives and instructors from throughout the state and Chairman R. C. Wiley said plans already are under way for another similar course next summer. The California State Commission for Vocational Education was co-sponsor.

Trade figures participating as lecturers and instructors included: Russell H. Rhoades, The Linde Air Products Co., San Francisco; Lee Reay and A. H. Butler, Linde men from Los Angeles; H. R. Strickland, Haynes Stellite Co., San Francisco; Carl Geiger, Air Reduction Pacific Co., Los Angeles; K. V. Lutz, All-State Welding Alloys Co., San Jose; R. J. Lafferty, Handy and Harman Co., Los Angeles; A. R. Wynn, Harnischfeger Corp., Los Angeles.

Demonstrations included uses of the oxyacetylene flame for braze welding, hard surfacing, flame hardening, wrinkle bending, heating and forming and machine flame cutting. There were other demonstrations in handling methods, industrial safety, arc welding training for casual users, automatic submerged-arc welding, low-temperature brazing alloys, high frequency in inert-gas-shielded-arc-welding and low-temperature brazing.

Most popular part of the program, however, was the late afternoon and evening practice and experiment time when Cal Poly's extensive welding shops were thrown open to use by short coursers under supervision of visiting trade men and Cal Poly instructors.

Hot Radiography

Sam Tour & Co., Inc. of 44 Trinity Place, New York City announce having contracted for the exclusive license to use and to sublicense the use of the McElroy-McNutt Process of Hot Radiography. Using this process, successful radiographs have been obtained while the metal being examined was at 900° F.

No longer is it necessary to wait until the metal cools down before it can be radiographed.

It is possible to radiograph during intermediate stages of welding without delays due to stress relieving and slow cooling. Better weld inspection together with a time saving is made possible by this process.

The utmost in safety to personnel and to equipment is necessary in connection with the pressure vessels used in power plants, oil refineries and synthetic chemical manufacturing plants. In these installations, where metals are joined by welding, stringent radiographic inspection is necessary. Hot radiography is the most efficient method yet developed for these installations. Many hours of construction time are saved.

Seventh Western Metal Show in Oakland Week of March 19th, 1950

The Oakland, Calif., Civic Auditoriums will be the scene of the 1951 Western Metal Congress and Exposition, March 19–23, the seventh to be held in the interests of the Western metal-working industries.

Management of the Western Metal Show will again be under the direction of William H. Eisenman, National Secretary of the American Society for Metals, sponsors of the event. Co-sponsoring the Congress activities will be approximately 20 cooperating technical societies whose interests apply to the oil, chemical, manufacturing, aviation, mining and other Western industries.

Heading the general committee of the 1951 Metal Congress and Exposition is Harry Lewis, Chairman of the Golden Gate Chapter of the American Society for Metals. Vice-Chairmen Bert Depew, General Electric; Philip McCaffery, General Metals Corp. and E. A. Daniels, Victor Equipment Co. (representing the AMERICAN WELDING SOCIETY), will share responsibilities with the committee's general secretary, Harry E. Krayenbuhl, Oliver United Filters, Inc.

Professor Earl R. Parker, University of California, will direct programming, and W. A. Fletcher, E. F. Houghton & Co., will handle publicity. On the committee for exhibits is G. B. Berlien, Industrial Steel Treating Co., with Paul G. Childs, Earle M. Jorgensen Co., in charge of entertainment and George A. Nelson, Shell Development, in charge of cooperating Societies.

Other committee members include Guy M. Winton, Allegheny Ludlum, for attendance; Tom Hutton, Thomas H. Hutton & Son, for Information and Registration; Charles Blesch, Natural Gas Equipment Co., for Housing and Fred I. Donievy, Caterpillar Tractor Co., for Plant Inspection.

The big event in March next will mark the second time that Oakland has played host to the thousands of metallurgists, engineers, production executives and management officials whose activities and talents have built within the eleven Western States one of the greatest metals producing and metals fabricating areas in the world. Those who recall the outstanding success of the Oakland meeting in 1947 may well expect an even greater Congress and Exposition in 1951 because of both the growth of the industry and the added strategic importance of the area in connection with National security.

1951 and 1952 Meetings A.S.T.M.

Announcement is made of the national meetings of the American Society for Testing Materials, for 1951 and 1952, as follows:

1951 A.S.T.M. Spring Meeting and Committee Week
Cincinnati, Ohio
March 5 to 9, inclusive

1951 A.S.T.M. Annual Meeting
Atlantic City, N. J.
June 18 to 22, inclusive

1952 A.S.T.M. Spring Meeting and Committee Week
Cleveland, Ohio
March 3 to 7, inclusive (probably)

1952 A.S.T.M. Annual Meeting
New York, N. Y.
June 23 to 27, inclusive

These men are working for you

Energetic, keen-minded JOHN G. SEILER, Tube Turns' Executive Vice-President and General Sales Manager, keeps a sensitive finger on the pulse of your piping needs.

Solid, wiry JOHN W. GREEN, Sales Manager of Tube Turns' Fittings Division, arrives in New York for confab with Eastern representatives.

Rangy, quick-smiling THOMAS H. PIKE, Jr., Assistant Sales Manager of Tube Turns' Fittings Division, awaits flight call for personal check on West Coast piping picture.

JOHN E. CHUMBLEY, slender, youngish Sales Manager of Tube Turns' Forgings Division, makes frequent field trips that pay off in better products, faster service.

MOST travel-minded group of American businessmen today are sales executives. Covering millions of air, rail, and highway miles each year, these modern Marco Polos have chucked the Ivory Tower attitude of their predecessors.

Like many another sales management team, John Seiler, Jack Green, Tom Pike and John Chumbley look upon service as the father of sales. "Our customers are smart," confides Seiler. "They don't just *buy*, they *discriminate!* Field trips are the best way I know to find out how we can serve them better. It takes plenty of leg work in this business. Your customer can usually give you some pretty solid ideas on product improvement. We've prospered because we listen to what he says . . . *in person!*"

Some 2200 distributor salesmen, the sales-engineering staffs of Tube Turns' 8 district offices, and the finest group of piping technicians in the industry, follow this customer-service policy to the letter. Results: Tube-Turn welding fittings and flanges are the best in the company's history; Tube Turns' customers get qualified help in utilizing its products more and more profitably.

"Be Sure You See The Double tt"

TUBE TURNS, INC.
LOUISVILLE 1, KENTUCKY

TUBE-TURN

TRADE MARK

In all the world there's only one TUBE-TURN Welding Fitting as shown by this trade mark... the right mark for every need in welding fittings and flanges.

Your nearby TUBE TURNS distributor can serve you right from stock. Call him for prompt delivery.

TUBE TURNS, INC., LOUISVILLE 1, KENTUCKY DISTRIBUTORS IN ALL PRINCIPAL CITIES

DISTRICT OFFICES: NEW YORK • PHILADELPHIA • PITTSBURGH • CHICAGO • HOUSTON • TULSA • SAN FRANCISCO • LOS ANGELES

In Canada... Tube Turns of Canada Limited, Chatham, Ontario

PERSONNEL

E. H. Ewertz

At a meeting of the Executive Committee of the AMERICAN WELDING SOCIETY, held in New York on Friday, June 7, 1950, the following Resolution was unanimously adopted:

"The AMERICAN WELDING SOCIETY was shocked and grieved to learn of the passing on April 26th of one of its members, E. H. Ewertz.

Mr. Ewertz was one of the founders of the SOCIETY and was a member of its predecessor, the Emergency Fleet Welding Committee. He was for years on the Board of Directors of the SOCIETY, and became its President in 1924. In his many years of service in the SOCIETY he probably accomplished more than any other man before or since.

Mr. Ewertz endeared himself to all who knew him and his passing leaves a large void.

"Therefore, the AMERICAN WELDING SOCIETY, by this Resolution, gratefully acknowledges his constructive and valuable contributions of time and knowledge and expresses its sincere sympathy to the members of his family and to his company associates.

Membership of Resolution Committee:
J. H. Deppeler
D. Arnott
A. G. Oehler

OBITUARY

Arthur E. Gaynor

Once again the grim reaper has struck and cut down one of the Founder Members of the AMERICAN WELDING SOCIETY. Arthur E. Gaynor died on May 24, 1950 at the age of 72 in the Orange Memorial Hospital, Orange, N. J.

Arthur E. Gaynor joined the John A. Roebling's Sons Co. in 1903. His unusual abilities were duly recognized and he rose steadily in the Roebling Co., becoming Assistant Manager of the New York Branch in 1934. In 1937 he was made Branch Manager and retired Dec. 31, 1944. Since that time he has been engaged in various personal enterprises as his interests covered a wide range including fisheries, farming and the like. He continued to serve the Roebling Co. from time to time on special tasks.

When the New York Section of the AMERICAN WELDING SOCIETY was formed in 1920 Arthur became a member of the Executive Committee and served in that capacity until 1933. He was elected Secretary-Treasurer of the Section, serving from 1920 to 1923. In 1925 he became Chairman of the Section.

Arthur Gaynor's warm personality made him a host of friends and his general ability attracted attention in the national affairs of the SOCIETY. He became a member of the National Board of Directors in 1925 and continued such service for a 15-year period. He was elected Senior Vice-President of the SOCIETY in 1928 and served in that capacity until 1930. He declined the Presidency of the SOCIETY as he was a modest individual and thought that the affairs of the Society could be better handled if the SOCIETY would select some outstanding industrialist for the office of President. However, once more in 1932 he was elected Senior Vice-President of the SOCIETY. Time and again Mr. Gaynor was called to serve as a member or Chairman of some committee of the SOCIETY. He rendered outstanding service on the Finance Committee of the SOCIETY and as Chairman of the Membership Committee. Arthur resided in East Orange, N. J. He was never married. He was a member of the Society of Naval Architects and Marine Engineers, Engineers' Club, the Downtown Athletic Club and a 32nd Degree Mason, Hope Lodge, East Orange.

OBITUARY

Frank A. Bond

Frank A. Bond, of Pittsburgh, Pa., died of a heart attack on Monday, July 3rd, at his summer home in Erie, Pa. Born Oct. 9, 1883, he was a native of Pittsburgh.

Mr. Bond, Vice-President and Secretary of The McKay Co., chain manufacturers, was prominent in the Chain Industry for a great many years. He became associated with the Standard Chain Co. in 1905 and later, during World War I, organized and formed the National Chain Co. of Marietta Ohio. He joined the McKay Co. in 1919,

where he held the position of Executive Vice-President and Secretary.

Mr. Bond was active in the American Institute of Mining and Metallurgical Engineers; AMERICAN WELDING SOCIETY; American Society for Testing Materials; American Society for Metals; Society of Automotive Engineers; American Supply and Machinery Manufacturers Association; American Hardware Manufacturers Association and The National Wholesale Hardware Association, and the Southern Wholesale Hardware Association.

He leaves his wife, Leila Stokey Bond; a son, Donald A.; a daughter, Mrs. Joseph S. Preston and three grandchildren.

Precision Welder & Machine Co. Names New Personnel in Sales

Robert Greer, former resistance welding engineer for Welding Engineering Sales Corp. and Carrier Corp., has been appointed District Representative for New York State outside of Metropolitan New York for Precision Welder & Machine Co., Cincinnati, Ohio. Mr. Greer will be located at 116 South Salina St., Syracuse, N. Y.

William Mumford, former assistant Welding Engineer for Lincoln Mercury Division of Ford Motor Co., has been appointed Sales Engineer for Precision Welder and Machine Co., with headquarters at Cincinnati.

Both are members of the AMERICAN WELDING SOCIETY.

Sciaky Promotions

George Palmer, former Dayton, Ohio Branch Manager, transferred to Chicago and western territory with Jerome Pinsky, Jack Graux and Lyle Noteboom assisting as Application Sales Engineers.

George Zeis was transferred from the Dayton branch to Chicago to function as coordinator between all sales offices, engineering and manufacturing.

Both are members of the AMERICAN WELDING SOCIETY.

$125 and 7 weeks saved, thanks to NI-ROD repair of cast iron speed reducer

When a mishap all but destroyed a vital coil-vat speed reducer, maintenance men of the M & R Dietetic Laboratories were faced with a serious problem.

A new speed reducer cost 135 dollars and would take 8 weeks to be delivered. Repairing the unit would require only a week, but the damage was so extensive that success seemed doubtful. Yet, there was so much to be gained that they decided to take the gamble.

The shattered speed reducer was sent to M & R's welding shop, where . . . using Ni-Rod® electrodes . . . their welding technicians succeeded in assembling the broken pieces.

The cost of the repair, including labor, was only 10 dollars, and the time required was 1 week. *This represented a net saving of 125 dollars and 7 weeks down time. A highly profitable operation, indeed!*

Experiences such as this . . . of time and money saved in welding cast iron with Ni-Rod electrodes . . . are daily occurrences at thousands of welding shops throughout the nation. The reason for Ni-Rod's popularity with these experienced welders is *dependability*. With Ni-Rod electrodes you get quick, sound, machinable welds in all grades of cast iron . . . usually without preheating or postheating. Ni-Rod works well in all positions; can be used with either AC or DC current.

The best way to find out about Ni-Rod's many advantages is to try it. Order a package today and discover for yourself why *4 out of 5 shops* re-order Ni-Rod, once they have tried it.

Your nearest INCO distributor stocks Ni-Rod in 3/32", 1/8", 5/32", and 3/16" diameters.

Coil-vat speed reducer repaired with Ni-Rod at M & R Dietetic Laboratories, Columbus, Ohio.

For welds you've never been able to make before . . . in high-phosphorous irons; heavy sections—

NI-ROD "55"

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street, New York 5, N. Y.

Charles W. Bryan Elected Head of Pullman-Standard

The election of Charles W. Bryan, Jr., of New York City as president of Pullman-Standard Car Mfg. Co., was announced recently by Champ Carry, president fo Pullman Inc. Pullman-Standard is the railway carbuilding subsidiary of Pullman Inc.

Bryan was formerly associated with Federal Shipbuilding and Dry Dock Co., of which he was vice-president and general manager in 1948 when its Kearny shipyard was sold to the United States Navy. In a progressive series of supervisory and executive positions with the shipbuilding company, he was active for many years in a wide variety of engineering, contracting and construction work involved in the plant and products of that organization.

In 1949, Bryan was loaned to the Economic Cooperation Administration and served in Italy with an ECA mission as consultant on shipbuilding and shipping matters. He also has been an active participant in the affairs of the American Society of Civil Engineers, the AMERICAN WELDING SOCIETY, the Society of Naval Architects and Marine Engineers and other technical organizations.

Carry, who was formerly president of Pullman-Standard, will continue to be associated directly with the company as chairman of its board of directors, and will continue as president and chief executive officer of Pullman Inc.

Kaufman Made Sales Manager

On July 1, 1950, The McKay Co. of Pittsburgh, Pa., manufacturers of commercial and industrial chains, arc-welding electrodes and chemical products, announced the appointment of Fred A. Kaufman as General Sales Manager. Mr. Kaufman succeeds Fred C. Smith who on the above date assumes the position of Special Assistant to the President, J. C. McKay.

Mr. Kaufman has been with The McKay Co. for a number of years. Immediately after his graduation from college as a Metallurgical Engineer, he was associated with Carnegie-Illinois Corp., Pittsburgh, Pa. He later joined the organization of Crown Can Co., Philadelphia, Pa., as Plant Metallurgist. His first association with The McKay Co. was in 1943 when he joined the McKay Research Fellowship at Mellon Institute of Industrial Research. Since then, he has successively been in charge of Technical Service and Research and Quality Control at the York, Pa. plant. For the past year and a half Mr. Kaufman has been Sales Manager of The McKay Co.'s Arc Welding Electrode Division located in Pittsburgh, Pa. In his new position as General Sales Manager, Mr. Kaufman will continue to have charge of the sales of McKay Arc Welding Electrodes, as well as the complete line of McKay chain and chemical products.

Mr. Kaufman is a member of the AMERICAN WELDING SOCIETY.

Radcliffe Joins Reid-Avery

E. E. Radcliffe is now associated with the Reid Avery Co., Inc., Dundalk, Baltimore 22, Md., as a Specialist on Submerged Melt Welding.

Mr. Radcliffe was formerly with the Unionmelt Division of the Union Carbide and Carbon Corp., for many years.

R. F. Johnson Gets New Post at Pullman-Standard

The appointment of Roy F. Johnson as manager of the sales and service engineering division of Pullman-Standard Car Mfg. Co., was announced today by T. P. Gorter, vice-president in charge of sales for the company.

As manager of the new division, Mr. Johnson will serve as liaison for the sales department of Pullman-Standard with the shops, production engineering and research. This division also will carry on the customer field service heretofore conducted by the research department.

Just Published!

An A to Z treatment of resistance welding

which points the way to big savings and increased production

REFLECTING the experience of hundreds of leading shops, this book points the way to the design and production of more efficient metal-made products. It gives you a *complete* picture of resistance welding—what it is; the equipment and materials used; the design, tooling, and production techniques that afford big savings in materials, costs, manpower, etc. Spotlighting modern developments and methods, it shows you thousands of dollars in cost savings.

RESISTANCE WELDING

Designing, Tooling, and Applications

By Wallace A. Stanley

Consultant on Product Design, Tooling, and Manufacturing Operations, *Progressive Welder Company*, Detroit

329 pages, 792 illustrations, 8½x11, $7.50

THIS book brings you valuable shop and tooling "know-how" that you can apply in planning and developing products for resistance welding. It explains how to design for spot welding, projection welding, seam welding, and flash butt welding, and discusses tooling, handling, and materials control for various operations.

Provides practical information on the HOW and WHY of:

- indexing mechanisms
- low-temperature joining
- butt welds in tension
- shuttle-action welding machines
- multistation welding machines
- portable welding equipment
- rotary-indexing welders for multi-angle welding heads
- dies and clamps for butt and flash butt welders
- hydromatic spot-welding machines
- welding dissimilar metals
- the secondary "loop"
- "push-pull" welds
- seam-welder drives
- destructive evaluation tests
- rivets versus spot welds
- importance of water deflector tubes
- engineering specifications, etc., etc.

792 photographs and line drawings, picture tools, methods, and procedures which have resulted in tremendous savings in the fabricating industries. Combined with the book's clear, easy-to-read explanations and descriptions, they make up a manual of practical information and process data that reflects the best practice in the field.

You'll find in this book simple but complete treatment of hundreds of topics from tooling and fixtures, to sequence of welds—from standard tips and holders to general considerations—from tension tests, to spot welding applications.

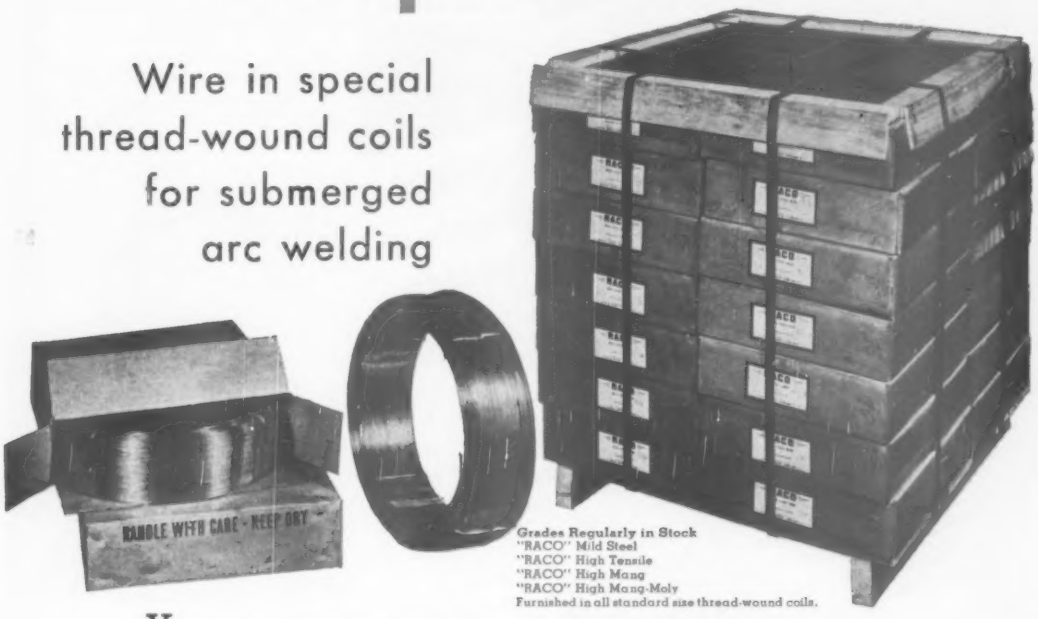
AMERICAN WELDING SOCIETY

33 West 39th Street

New York, 18, N.Y.

A superior PRODUCT AT A competitive PRICE!

Wire in special thread-wound coils for submerged arc welding



Grades Regularly in Stock
"RACO" Mild Steel
"RACO" High Tensile
"RACO" High Manq
"RACO" High Manq-Moly
Furnished in all standard size thread-wound coils.

YOU profit by these RACO extras: Rigidly inspected high quality steel. Beautiful bright copper coating. All coils uniformly thread-wound and uniform in weight, width, inside and outside diameters to fit your reels. Thread-winding and prebent controlled curvature eliminates unwinding entanglements, waves, kinks. Assures deposition only in welding vee. Assures uninterrupted production.

Wire is drawn, copper coated, and mechanically thread-wound in one continuous operation immediately preceding shipment, on machines specially developed by us.

RACO coils are packed and sealed in heavy cartons, and palletized to prevent damage in transit, improper stacking or torn wrappers which result in rust and dirt. Coils are not distorted out of shape by rough handling. Steel-strapped palletized unit-shipments prevent mixing with other consignments at transfer terminals while en route; avoid filing of claims, etc. Fifty-six 25-pound coils, twenty-eight 75-pound coils, eight 150-pound coils per unit pallet at no extra cost to you.

Our special packing and shipping methods reduce your handling, disbursement, and storekeeping costs. Save storage space. Provide easy identification as to type and diameter of wire. Our superior quality and coiling assures superior welds and reduces cost per pound of deposited metal.

The **REID-AVERY COMPANY**
INCORPORATED
DUNDALK BALTIMORE 22 MARYLAND

It is the sales policy of The Reid-Avery Company, Inc., to market our products exclusively through distributors and agents. • *Members of* THE AMERICAN WELDING SOCIETY *and* THE NATIONAL WELDING SUPPLY ASSOCIATION

ARCOS HAS ALL THREE For Dependable Stainless and High Tensile Welds

Whatever type of stainless or high tensile welding you do, you will find that ARCOS has the electrode or wire that will give uniformly dependable welds.

You can rely on Arcos products because Arcos has specialized in this type of welding for 20 years. All Arcos production is geared to the more exacting requirements of stainless, low alloy high tensile, monel, nickel and bronze welding and Oxyarc® cutting. Rigid quality controls insure uniformly good results.

Try Arcos electrodes on that tough welding job and save rewelding costs. Try Oxyarc cutting on the stainless, non-ferrous or cast iron cutting jobs. Electrodes available in all standard grades and sizes from distributor stocks.

ARCOS CORPORATION

1500 South Fiftieth St., Philadelphia 43, Penna.

WELD WITH ARCOS

Specialists in Stainless, Low Alloy and Non-Ferrous Electrodes

Sawyer Promoted

Effective July 1, 1950, A. W. Sawyer was appointed Assistant to the Vice-President of The Lincoln Electric Co. of Cleveland, Ohio. Sawyer is a graduate of Cornell University where he received his degree in Mechanical Engineering. He had been previously employed by Bell Aircraft of Buffalo.

Sawyer joined Lincoln after his graduation from Cornell and worked in the factory as a Methods Engineer. Prior to his present appointment he was in charge of development and production of welding instruction aids. In his present position Sawyer will handle government bids and contracts and also conduct Lincoln's educational activities.

A. W. Sawyer is a member of the AMERICAN WELDING SOCIETY and at Cornell he was elected to the senior honorary society, Sphinx Head.

Tesmen Joins Tempil®

Tempil® Corp. announces the appointment of Arthur B. Tesmen as Sales Engineer.

Tempel® customers and distributors who encounter problems in temperature determination and temperature control will be able to avail themselves of Mr. Tesmen's excellent background and experience in metallurgy as well as welding procedures.

Before joining Tempil® Corp. Mr. Tesmen was with North American Philips Co., Inc. in charge of Sales-service, promotion and development of their Contact Electrodes and other welding products. Prior to that he was with Crucible Steel Co. of America as Metallurgical Engineer and with the Industrial Laboratory of the Philadelphia Navy Yard as a Welding Engineer.

Mr. Tesmen graduated from the University of Michigan in 1939 with a B.S. degree in metallurgical engineering and did postgraduate work in metallurgy at Lehigh University. He is a member of the AMERICAN WELDING SOCIETY, the American Society for Metals and the American Institute of Mining and Metallurgical Engineers.

PAGE *Welding* ELECTRODES

Page-Allegheny *Stainless Steel*

AC or DC

ARC
—stable even at very low amperage

SLAG
—clean, easily removed

COATING
—resists cracking down to very short stubs

SELECTION
—complete line for welding every type of stainless

DELIVERY
—prompt from warehouses in Chicago, Denver, Houston, Philadelphia, San Francisco and the factory at Monessen, Pa.

ACCO

Monessen, Pa., Atlanta, Chicago, Denver, Detroit, Los Angeles, New York, Philadelphia, Portland, San Francisco, Bridgeport, Conn.

TRADE MARK

PAGE STEEL AND WIRE DIVISION
AMERICAN CHAIN & CABLE

Get in touch with your PAGE Distributor

NEW LITERATURE

Welding Copper

Reprints of Chapter 31 from the *Welding Handbook* (published by the AMERICAN WELDING SOCIETY) covering the welding of copper and copper alloys are available.

This chapter includes the joining of these materials by the various welding processes. Information contained is up-to-date and can be considered as authoritative reference data.

Copies will be furnished gratis by Ampco Metal, Inc., 1745 S. 38 St., Milwaukee 46, Wis.

A.S.T.M. Specification for Steel Flat Products

This new compilation of A.S.T.M. Standards, dated March 1950, includes 39 specifications for steel flat products: plate, sheet, strip and related materials. The materials covered are widely used for structural purposes, and for boiler and pressure vessels. For convenience, a number of the standards relating to stainless steel, wrought iron and metallic-coated sheets are given also.

These specifications are reprinted in the compilation, from the *1949 Book of A.S.T.M. Standards*, to provide in convenient compact form, for those interested, the standards on flat-steel products.

The 204-page book, in heavy paper cover, can be obtained from Headquarters of American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., at $2.25 each.

Resistance Welding

Resistance Welding—Designing, Tooling, and Applications, by Wallace A. Stanley, Consulting on Product Design Tooling, and Manufacturing Operations. Progressive Welder Co., Detroit, Mich. Price $7.50. Published by McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 18, N. Y. *Editorial Note:* This book may be purchased thru the AMERICAN WELDING SOCIETY.

Here is valuable job knowledge which points the way to the more economical and efficient design and production of metal-made products. Reflecting the experience of hundreds of leading shops, this book explains resistance welding from A to Z—what it is; the equipment and materials used; the design, tooling and production techniques that afford big savings in materials, costs, man power, etc.

Spotlighting modern developments and methods, this book brings you valuable shop and tooling "know-how" that you can apply in planning and developing products for resistance welding. It explains how to design for spot welding, projection welding, seam welding and flash butt welding, and discusses tooling, handling and materials control for various operations.

Seven hundred and ninety-two photographs and line drawings picture tools, methods, and procedures which have resulted in tremendous savings in the fabricating industries. Combined with the book's clear, easy-to-read explanations and descriptions, they make up a manual of practical information and process data that reflects the best of practice in the field.

Solders and Soldering

Soldering is one of the easiest and most satisfactory methods of joining metals that can be used with equal success by both the handyman and the professional. The National Bureau of Standards has just published a circular, *Solders and Soldering*, which describes in detail types of solders and soldering procedures. This circular is now available from the U.S. Government Printing Office.

The three classes of solders treated are soft solders, precious metal solders and common brazing solders. Instructions are given for the proper use of each type of solder for joints of the required strength. The selections of fluxes, which can be as important as the choice of solder, is adequately discussed.

All common soldering alloys are listed and their component elements, together with their melting ranges, are given. Illustrations of different types of soldered joints are shown, and types of soldering equipment are described and illustrated.

Circular 492, *Solders and Soldering*, 12 large double-column pages, is available from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., for 15 cents a copy. Remittances from foreign countries must be made in United States exchange and must include an additional sum of one-third the publication price to cover mailing costs.

The Inelastic Behavior of Engineering Materials and Structures

The Inelastic Behavior of Engineering Materials and Structures is the title of a book by Alfred M. Freudenthal. Published by John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y.

This book develops a fundamental approach to materials research—an approach based on the analysis of the underlying unifying principles. It covers all aspects of the subject that are important in: (1) problems of research in mechanical properties and behavior of materials, (2) problems of mechanical testing of engineering materials and of the evaluation of test results with regard to performance in service (3) problems of design of structures and machine parts and the theory of technological processes.

The book follows a logical arrangement. The Introduction discusses the purpose of the study of mechanical behavior and the basic concepts and definitions. Parts A and B develop the structural and phenomenological framework of the mechanics of inelastic behavior of engineering materials. Part C deals with specific problems of inelasticity, with design of structures and machine parts under various conditions, and with mechanical testing.

Throughout the book the author uses the pictorial physical approach based on the modified Bohr model of atomic structure, rather than the rigorous but non-pictorial quantum concepts of modern solid-state physics.

Lincoln Directory

The Lincoln Electric Co., Cleveland, 1, Ohio, has issued a new 8-page *Directory of Welding Supplies, Bulletin 467*. Featured are electrode holders, ground clamps, arc torches, connectors, shields, cables and electrodes. Copy available on request.

Strength of Wrought Steels at Elevated Temperatures

This 1950 Report giving a great wealth of information and data on the chemical and physical properties of wrought steels at elevated temperatures, prepared by R. F. Miller and J. J. Heger, of the Carnegie-Illinois Steel Corp., was issued under the auspices of the A.S.T.M.-A.S.M.E. Joint Committee on Effect of Temperature on the Properties of Metals, by the American Society for Testing Materials.

Largely a graphical presentation, the data for the Report were gathered from a wide variety of sources which are noted in the book. One of the important features is the fact that standard commercial grades of steel are covered, the latest data on tensile, creep and rupture properties being given.

The report is in two sections, the first 52 pages covering the plain carbon and alloy steels containing molybdenum and up to 3% chromium; the second part covers the ferritic and austenitic steels with more than 5% chromium. The latter includes many of the stainless varieties. Many of the steels for which data are given are covered in A.S.T.M. specifications, the applicable standards being noted.

In order that the large number of curves and data points thereon would show up clearly and in appropriate size for ease of reading, the publication is issued in page size 8½ by 11 in. There are 112 pages, and the book is bound in heavy paper cover.

Copies can be procured from American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., or from A.S.M.E. Headquarters, at $3.00 each.

the mountain comes to

Mohammed!

THOUSANDS OF MEN* INTERESTED IN METALS VISIT THE

METAL SHOW

TO GET YOUR HELP IN ACHIEVING "ECONOMY-IN-PRODUCTION"

● The Metal Show is Tops! At the Metal Show in Cleveland last fall 35,588 men viewed the exhibits—for years, the attendance of Executives, Metal Engineers and Buying Officials has exceeded 30,000. The Metal Show in Chicago next October will draw at least 30,000 men that are interested in anything and everything that will help them achieve "Economy-in-Production".

And these men BUY! For example: 22% of last year's visitors decided to buy something they saw at the Metal Show. 10% bought something different from what they planned after seeing it at the Metal Show. And 20% completed a decision to buy something after seeing it displayed at the Metal Show.

Nearly 400 manufacturers will exhibit at the Show. Be among them and secure your space NOW. Write, wire or phone W. H. Eisenman, Managing Director, 7301 Euclid Avenue, Cleveland 3, Ohio, (UTah 1-0200) for floor plan and space reservation.

***35,588 Metal Men attended the Show in Cleveland last fall. Attendance Report No. 4 tells why they came, when they came, how long they stayed and what they thought. If you haven't received your copy, write for it.**

METAL SHOW

OCT. 23-27, 1950

INTERNATIONAL AMPHITHEATRE, CHICAGO, ILL.

Sponsoring Societies

American Society for Metals — American Welding Society

Institute of Metals Div.—A.I.M.E. — Society for Non-Destructive Testing

Announcing

The EUTECTIC WELDING ALLOYS CORPORATION

$1000.00 PRIZE COMPETITION

To Welding Engineers, Researchers, Metallurgists, Instructors, University Students and all others qualified . . .

for papers on

Technological and Research Aspects, Advances and Advantages of the Use of Lower Melting (lower than parent) Filler Metals in the Non-fusion Welding Processes.

R. D. Wasserman
President

AWARD FUND

FIRST PRIZE $500.00
SECOND PRIZE 300.00
THIRD PRIZE 200.00

Rules of the Competition

(1) The competition is open to all persons qualified to present basic principle, theory or the results of practical research and experience in the field of non-fusion "lower melting" (lower than parent) filler metals in welding, except employees of Eutectic Welding Alloys Corp., its advertising agencies, and members of their families.

(2) Participants in the competition may submit welding papers on one or more of the following subjects:

(a) Oxy-acetylene, low melting filler
(b) Oxy-fuel gas, low melting filler
(c) Brazing and bronze welding
(d) Hard facing and resurfacing, with a low melting filler

The welding application may be by torch, furnace induction, carbon arc or electric arc.

(3) Papers are to be presented in English and should be typewritten.

(4) Papers should be confined specifically to the field defined above and may be documented with photographs, test data or other material to substantiate and verify the thesis presented or described.

(5) All papers must be the original, previously unpublished work of the participant and must bear his name and address.

(6) Papers will be judged by The Jury and Committee of Awards on the basis of the merit of the theory or practice presented. Decision of the judges will be final. All entries and ideas therein become the property of Eutectic Welding Alloys Corporation and none will be returned.

(7) The competition opens Sept. 1, 1950 and closes May 31, 1951 midnight. All entries must be postmarked on or before that date.

(8) Winners of awards will be notified by mail within approximately 60 days after the close of the competition. Complete list of winners will be sent to all participants requesting it.

THE JURY and COMMITTEE of AWARDS

Dr. Th. I. Leston, Vice President, Eutectic Welding Alloys Corporation
Prof. Otto H. Henry, Dept. of Metallurgy, Polytechnic Institute of Brooklyn
Dr. Robert Humphrey, Vice Chairman, American Society for Metals

Papers should be directed to:

Welding Research Competition
EUTECTIC WELDING ALLOYS CORPORATION
40 Worth Street, New York 13, N. Y.

Guide to Steel Selection

This 4-page bulletin lists all popular grades of hot-rolled and cold-finished carbon and alloy steel bars, giving principal characteristics, mechanical properties and uses. It is intended to serve as a quick, convenient and helpful guide to the selection of the most suitable as well as the most economical qualities of bar steel for the various jobs that come up in the average shop. Prepared especially for jobbing and repair shops and maintenance departments, this guide also has proved useful to production men and designers. For a free copy address Joseph T. Ryerson & Son, Inc., Post Office Box 8000-A, Chicago 80, Ill.

Ampco News

Copies of the second quarterly edition of the Ampco Welding News are available upon request.

The articles cover the salvaging of cast-iron tumbler gears, successful welding of large galvanized recirculating air-duct systems, extended life for forming dies by overlaying and practical method of rebuilding screw conveyor shafts.

Write Ampco Metal, Inc., 1745 S. 38 St., Milwaukee 46, Wis. and copies will be forwarded gratis.

Zapffe Book Given High Rating

The Science and Technology Division of the New York Public Library has announced its selections for the "100 Best Technical Books of the Year." Included on the list is a book by Dr. Carl A. Zapffe, Lehigh '34, entitled: *Stainless Steels—An Elementary Text for Consumers.*

The announcement was made in the Technical and Business Book issue of the *LIBRARY JOURNAL.*

Stainless Steels was written by Dr. Zapffe at the request of the American Society for Metals and published by that organization as their official text on this important branch of metallurgy. The book is a comprehensive review of the subject, but written in terms which are as simplified as possible, to explain to the less technically trained reader the unusual properties of these alloys and the best manner in which they should be worked and used. The book is particularly interesting for its history of the development of stainless steels, showing that their unique properties had been discovered far earlier than commonly presumed.

During the recent war, Dr. Zapffe was Assistant Technical Director of the Rustless Iron and Steel Division of the Armco Steel Corp. in Baltimore, one of the World's largest producers of stainless steels. Since 1945 he has been working on special research projects for the United States Navy under Contract with the Office of Naval Research. He lives with his wife and five children at 6410 Murray Hill Road in Baltimore. He is a member of the AMERICAN WELDING SOCIETY.

Welding Connectors

Joy announces completion of a new two-color flyer No. 8M-1 that pictures and describes a new family of Welding Connectors. According to their report these plugs engage easily, yet cannot be accidentally disengaged. Molded as a unit of Neoprene and vulcanized to cable they are shatter proof, jerk resistant and water tight. The new flyer describes results observed when 500 lb. was suspended by a pair of these new connectors for 24 hrs.

It also describes String-a-lite portable lighting lines for industrial use.

Copies will be forwarded to those addressing requests to Mines Equipment Div., Joy Mfg. Co., Dept. W4, Henry W. Oliver Bldg., Pittsburgh 22, Pa.

A.S.T.M. Symposium on Evaluation Tests for Stainless Steels

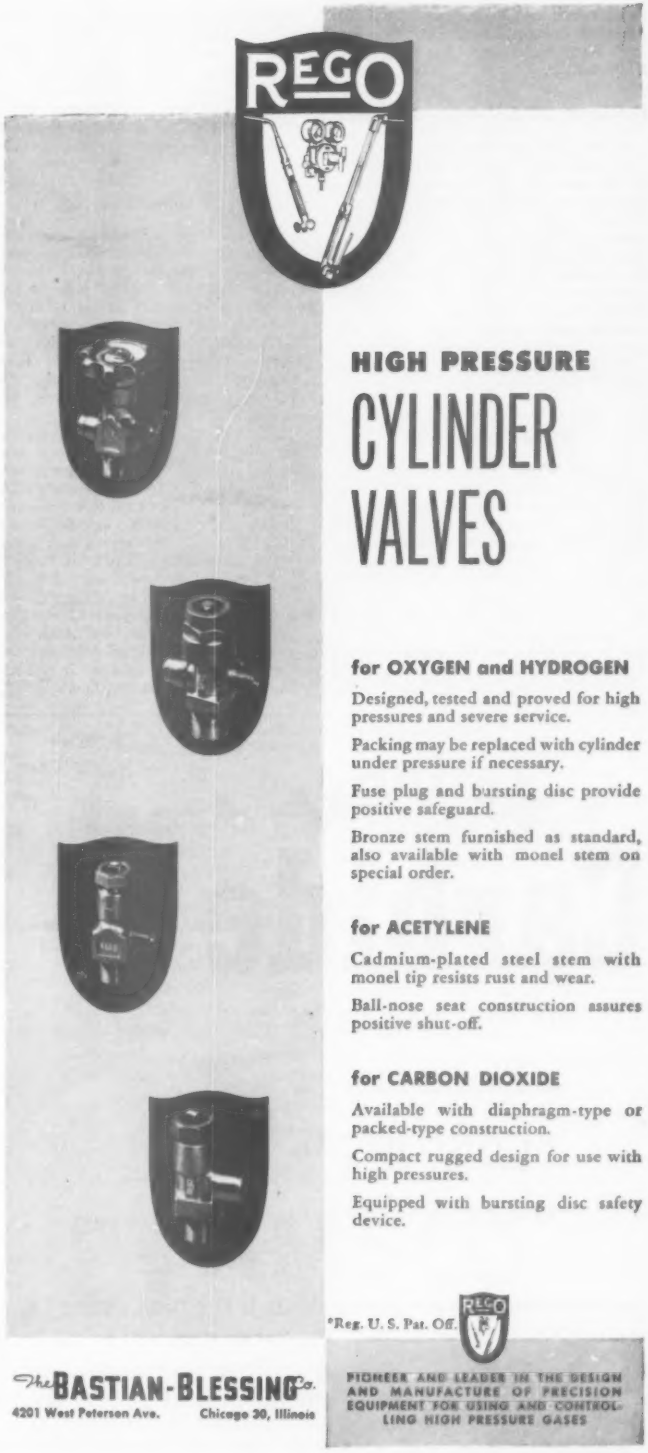
Issued in May 1950, this symposium held at the 52nd Annual Meeting of the American Society for Testing Materials under the auspices of Committee A-10 on Iron-Chromium-Nickel and Related Alloys presents a critical appraisal of some of the testing methods that are in regular use for evaluating certain corrosion-resistant characteristics of these stainless steel alloys. Special attention was focused on two features: first, the significance of results of the laboratory evaluation tests with relation to practical experience under diverse service conditions and second, the effects on behavior of the alloys in test, and in use, of lowering carbon contents to extremely low limits.

The Symposium attracted as authors and as discussers many of the major contributors to our knowledge of the metallurgical and corrosion-resistant characteristics of the alloys in question.

Following an extensive Introductory Summary, with detailed table of solutions used to detect sensitization, comparison of results of evaluation tests and other pertinent data including a five-page table of effects of stress relief and stabilizing anneals on corrosion as prepared by F. L. LaQue, the following subjects are covered: Present Knowledge of Low-Carbon 18-8 (Gillett); Corrosion Resistance and Properties of Low-Carbon Austenitic Steel (Buck, Heger, Phillips and Queneau); Accelerated Corrosion Testing of Weldments (Bloom and Carruthers); An Appraisal of Methods for Evaluating Corrosion Resistance (Brown, DeLong and Myers); Tests for Intergranular Susceptibility (Ebling and Scheil); Influence of Carbon and Molybdenum on the Intergranular Corrosion Resistance (Binder and Brown); Comparative Corrosion Resistance in Various Acids (Mears, Larrabee and Fetner); Comparison of Plant Corrosion Test Results with Huey and Strauss Tests (Teeple); Some Plant Corrosion Tests of Welded Steels (Comstock) and Testing Multiple Specimens in a Modified Boiling Nitric Acid Test (DeLong).

There is a great deal of tabular and graphic material in the publication and many illustrations.

Copies of this 236-page book, in heavy


REGO
HIGH PRESSURE
CYLINDER
VALVES
for OXYGEN and HYDROGEN
Designed, tested and proved for high pressures and severe service.
Packing may be replaced with cylinder under pressure if necessary.
Fuse plug and bursting disc provide positive safeguard.
Bronze stem furnished as standard, also available with monel stem on special order.
for ACETYLENE
Cadmium-plated steel stem with monel tip resists rust and wear.
Ball-nose seat construction assures positive shut-off.
for CARBON DIOXIDE
Available with diaphragm-type or packed-type construction.
Compact rugged design for use with high pressures.
Equipped with bursting disc safety device.
*Reg. U. S. Pat. Off.
The BASTIAN-BLESSING Co.
4201 West Peterson Ave. Chicago 30, Illinois
PIONEER AND LEADER IN THE DESIGN AND MANUFACTURE OF PRECISION EQUIPMENT FOR USING AND CONTROLLING HIGH PRESSURE GASES

paper cover, can be procured from the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., at $2.50 each.

Daylight Fluorescence Detector

Folder 48-5/50 describes new ultraviolet light source with inbuilt dark chamber to make possible fluorescence detection and comparison in daylight. Portability is shown in applications to ore exploration, oil detection and nondestructive material testing with glow techniques. Illustrations show the self-energized unit in field use, an exploded view reveals the construction and design and a tabulation provides data on size, weight, price and spectral frequency of operation.

Menlo Research Laboratory, P. O. Box 522-CT, Menlo Park, Calif.

Rexarc Literature

The Sight Feed Generator Co. has prepared and now has ready for distribution new literature covering its manufacture of Rexarc, Rex-A-Lite and Rex-Tung hard facing and manganese rods and electrodes for oxyacetylene and electric-arc application. Included are descriptions of various rods and electrodes and a listing of hundreds of hard-surfacing applications and recommended rods for each. Coverage is also given on the firm's series of Tungsten Carbide Tubes and Peas. Technical data on the running of hard-facing electrodes and some hints about welding on manganese make this literature interesting and informative reading for welding shop owners, manufacturers and users of machinery subject to wear, impact and abrasion. Literature will be sent on request by The Sight Feed Generator Co., W. Alexandria, Ohio.

Welded Tubing

The structural advantages, methods of fabricating and characteristics of welded steel tubing are discussed in a new 12-page, illustrated booklet published by Armco Steel Corp., Middletown, Ohio.

Armco welded-steel tubing stresses the fact that tubing gives the utmost structural efficiency per pound of metal. Sketches show how this works when tubing is used either as a beam or a column.

The booklet outlines the characteristics of tubing—excellent finish, close tolerances, uniform mechanical properties—and shows a variety of uses where tubing has been effectively used to cut manufacturing costs, reduce weight, increase strength and improve appearance.

Complete information is included on how hot and cold rolled as well as Zincgrip and Aluminized tubing is supplied—size limits, finish, tolerances and properties—and how it should be ordered.

Copies of this handy reference on welded steel tubing can be obtained from Armco Steel Corp., Middletown, Ohio.

Story of Aluminum

The many amazing uses for aluminum are described in simple nontechnical language in the new book, *The A-B-C's of Aluminum*, just published by Reynolds Metals Co. The complete story of aluminum is presented—how the magic of chemistry and electricity turn clay into the bright metal products we see all about us.

The text of the A-B-C's is divided into three principal sections. "A" is for Alloys, the big family of metals called "aluminum," their production and fabrication; "B" is devoted to Benefits, the many natural advantages of aluminum and how they serve us; "C" covers Consumption, the many new and amazing uses for aluminum today and its fascinating potentials for tomorrow.

A special feature is the series of 69 pictures and charts. These are arranged in sequence to present a pictorial story showing how aluminum is produced from raw ore, made into metallic aluminum, and then processed to form sheet, rod, bar and other aluminum mill products. In addition, pictures of typical fabricating operations such as welding and forming are included.

This 96-page, 6 x 9-in. book is complete with tables of contents and in itemized cross index. Both cover pictures and text. A wire binding allows the book to lie flat when open.

The A-B-C's of Aluminum was written and produced by G. W. Birdsall. It is

National
Carbide
IN THE RED DRUM
EFFICIENT
ECONOMICAL
DEPENDABLE

FOR WELDING and CUTTING
Use National Carbide in the Red Drum
Write us for information as to nearest available stock.
60 E. 42nd St. NATIONAL CARBIDE COMPANY New York 17, N.Y.
A Division of Air Reduction Co., Inc.

the fast,

low-cost way

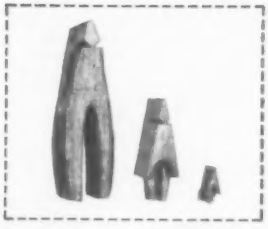
to get

worn teeth

back in service!

1. Worn tooth . . . 2. Plus AMSCO Tooth Repointer . . . 3. Equals like-new tooth—ready for service!

AMSCO® tooth repointers



AMSCO Repointer Bars

3 teeth partially rebuilt with AMSCO Repointer Bars to show sectional view of welding method. These Repointer, or Wedge Bars, are also made in many shapes and sizes. Apply AMSCO Economy Hardface to the rebuilt tooth *—for as much as 3 times longer service!*

● Here's a typical example of a badly worn dipper tooth completely restored to service . . . simply by welding on the AMSCO Cast-To-Size Tooth Repointer. The result is like-new service life and efficiency, plus a long-wearing tooth of Manganese Steel—the steel that actually work-hardens in service. Cost? *Far less than replacement!*

Wherever equipment has teeth that wear, more and more owners are using money-saving AMSCO Tooth Repointers . . . available in a wide variety of styles and sizes.

Get all the facts! Write today for Bulletin W-10-A —showing complete instructions for use.

put LIFE into service with

AMSCO®
WELDING PRODUCTS

AMERICAN Brake Shoe COMPANY

AMERICAN MANGANESE STEEL DIVISION
399 EAST 14th STREET • CHICAGO HEIGHTS, ILL.

sent without charge to anyone in the metal-working industry requesting it on company letterhead. Address all requests to Reynolds Metals Co., 2500 S. Third St., Louisville 1, Ky.

Aluminum-Alloy Sections for Road Vehicle Bodies

A new brochure marks an important step taken by the aluminum industry, in arranging to produce new extruded sections that will greatly assist road vehicle designers and builders.

The existence of a wider range of sections supplied from stock dies—and readily obtained—opens up a way to improved design of road vehicle bodies without the attendant difficulties of extra costs for special extrusions, and delay in obtaining them. Later difficulties of replacement in repair work, and the need to carry large stocks, are also removed.

A total of 32 sections is described, including 15 from B.S. 1161; "Aluminum Alloy Sections," and the data include weight per foot run, dimensions and geometrical proprties, and—for ten types of vehicle body—applications to cross bearers, crib rails, columns, corners, posts, etc.

Published by the Aluminum Development Assn., 33 Grosvenor St., London, W. 1.

Low-Temperature Brazing News

Bulletin 51 published by Handy and Harman, 82 Fulton St., New York 7, N. Y., describes a number of new and interesting applications of silver brazing. Copy available on request.

A.S.T.M. Data on Corrosion and Heat-Resistant Steels and Alloys

These new tables of data on the compositions and properties of the wrought corrosion-resistant and heat-resistant chromium and chromium-nickel steels and alloy castings have been assembled by Subcommittee I on Classification of Data, of the American Society for Testing Materials Committee A-10 on Iron-Chromium-Nickel and Related Alloys.

Data were collected and tabulated by Russell Franks, J. W. Juppenlatz, V. N. Krivobok, F. L. LaQue and E. A. Schoefer; and edited by F. P. Peters.

The publication brings up-to-date a previous compilation on wrought stainless alloys and includes a comprehensive new section devoted to cast alloys. The data have been divided into two parts: Part I on Wrought Alloys and Part II on Cast Alloys.

The data for the different steels have been condensed to the simplest form to provide a ready reference for both the maker and user of the steels.

Copies of this 84-page publication, heavy paper cover, can be procured from the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., at $2.50 each.

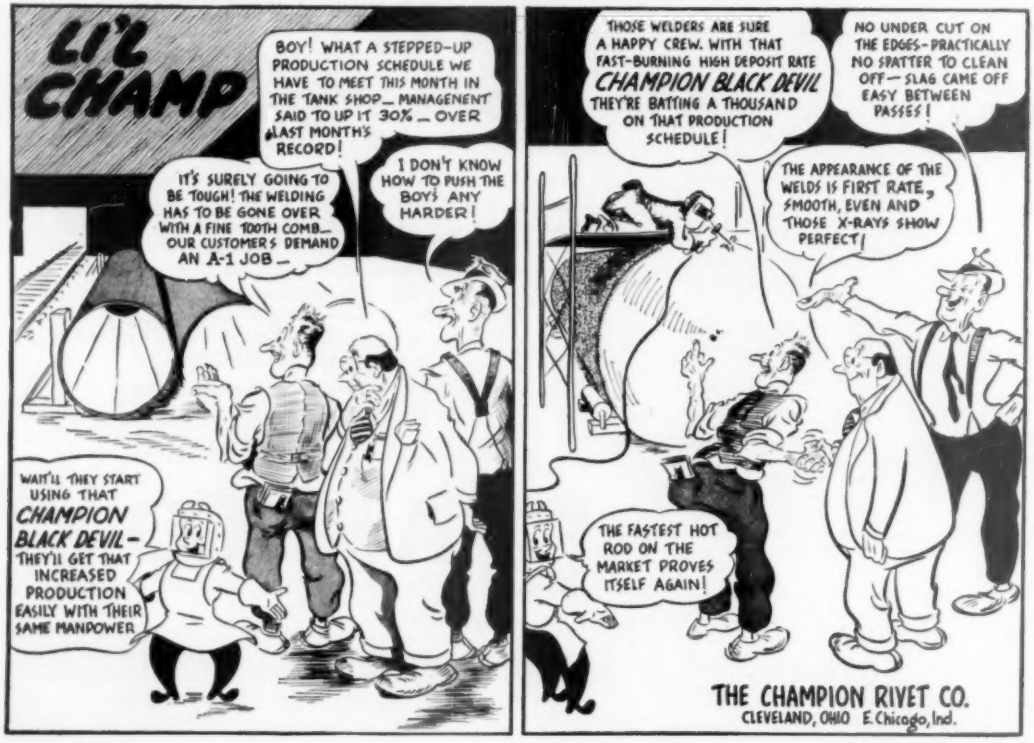
Employment Service Bulletin

Services Available

A-608. Electrical Engineer, B.S. degree. 10 years' experience as a service and development engineer for a resistance-welding machine manufacturer. Desire position in connection with plant engineering, development or processes engineering.

A-609. Available, Resistance Welding Engineer, pre-war and post-war experiences include design, development, field engineering, sales, research, and production welding supervision. Positions held: Assistant chief engineer, development and consulting engineer, technical advisor as engineer in charge of welding for large aircraft company, division sales manager. Geographical location of future employment unimportant.

A-610. Metallurgical Engineer desires position. Recent graduate as Metallurgical Engineer. Age 38, married, two children. Working in Production Metallurgical Laboratory important aircraft company on welding and heat treating as practiced in the plant.


LI'L CHAMP
BOY! WHAT A STEPPED-UP PRODUCTION SCHEDULE WE HAVE TO MEET THIS MONTH IN THE TANK SHOP— MANAGEMENT SAID TO UP IT 30% — OVER LAST MONTH'S RECORD!
IT'S SURELY GOING TO BE TOUGH! THE WELDING HAS TO BE GONE OVER WITH A FINE TOOTH COMB— OUR CUSTOMER'S DEMAND AN A-1 JOB —
I DON'T KNOW HOW TO PUSH THE BOYS ANY HARDER!
WAIT'LL THEY START USING THAT CHAMPION BLACK DEVIL — THEY'LL GET THAT INCREASED PRODUCTION EASILY WITH THEIR SAME MANPOWER
THOSE WELDERS ARE SURE A HAPPY CREW. WITH THAT FAST-BURNING HIGH DEPOSIT RATE CHAMPION BLACK DEVIL THEY'RE BATTING A THOUSAND ON THAT PRODUCTION SCHEDULE!
NO UNDER CUT ON THE EDGES- PRACTICALLY NO SPATTER TO CLEAN OFF— SLAG CAME OFF EASY BETWEEN PASSES!
THE APPEARANCE OF THE WELDS IS FIRST RATE, SMOOTH, EVEN AND THOSE X-RAYS SHOW PERFECT!
THE FASTEST HOT ROD ON THE MARKET PROVES ITSELF AGAIN!
THE CHAMPION RIVET CO.
CLEVELAND, OHIO E. Chicago, Ind.

YOU CAN BE SURE.. IF IT'S
Westinghouse

NEW D-C WELDER
SAVES $126 A YEAR IN POWER COSTS!

★ **NO-LOAD LOSS OF ONLY 500 WATTS...** compared to 2480-3600 watts on a conventional motor-generator welder.

★ **ENDS WELDER NOISE!** Lightweight, quiet selenium rectifier replaces old noisy motor generator.

★ **SIMPLICITY SLASHES OPERATING COSTS.** The new Westinghouse has only 3 basic elements ... transformer, reactor and rectifier. Saves motor and generator maintenance costs.

★ **SMOOTHER WELDING...** Less arc blow ... easier arc striking ... better weld quality.

FREE TRIAL!

We'll arrange DEMONSTRATION OR TRIAL INSTALLATION of the new Westinghouse D-C Welder at no cost to you. Write today. Westinghouse Electric Corporation, Dept. DC16, P. O. Box 868, Pittsburgh 30, Pennsylvania. J-21596

Westinghouse
D-C Welders

NEW PRODUCTS

Ground Clamp

A new lightweight, low-cost ground clamp of 300 amp. capacity, the GC-3, has been developed by The Lincoln Electric Co. of Cleveland, Ohio.

The GC-3 is designed to provide a convenient, readily movable, yet solid ground connection for welding jobs where welding currents do not average over 300 amp. The new clamp not only cuts accessory costs for these jobs but also eliminates for welders the inconvenience of handling heavy-duty clamps on jobs where their extra capacity is not needed.

The clamp weighs only 1½ lb. and has a jaw spread of 2½ in. A heavy direct acting spring gives a positive, slip-proof connection with the work. The frame is made of pressed-steel construction. The jaws are made of a special steel and copper alloy, "Lincalloy," which is both highly conductive and highly resistant to wear. "Lincalloy" is manufactured by Lincoln Electric especially for ground clamp and electrode holder jaw use.

The GC-3 does not replace the Lincoln heavy-duty GC-5 which has a capacity of 500 amp.

A.-C. Industrial Welders

A complete new line of a.-c. transformer welders in which welding heat adjustment is accomplished electrically through an a.c.-d.c. reactor is being announced by The Hobart Brothers Co., Troy, Ohio.

The transformer has conventional primary and secondary windings, plus an additional winding which supplies current through a rectifier to provide d.-c. current for a.c.-d.c. reactor adjustment. All class B insulation is used, with glass-covered conductors, and with glass cloth between layers. None of the coils move and all parts are anchored firmly in place.

The a.-c. winding of the reactor is in series with the transformer secondary and the arc, providing the reactance necessary to adjust the welding current. The d.-c. winding takes current from the rectifier to saturate the iron of the reactor, providing fine adjustment of the welding current. This design also provides the "pre-surge" instantaneous arc striking, without the use of relays or other moving devices.

A standard rectifier is used to supply power to the reactor d.-c. winding and uses minimum power. It is of the low voltage type (about 20 v.) so that the voltage going through the rheostat under the operator's hand is very safe.

Due to the design of the transformer and lack of crowding in the roomy case, cool operation is inherent and no fan is necessary. This feature makes these welders completely free of moving parts.

These sets can be furnished for operation on single phase, 60 cycle supply current—either 220/440 dual voltage, 440/550, or 220/440/550 v. They can also be furnished for 50 cycles, if desired.

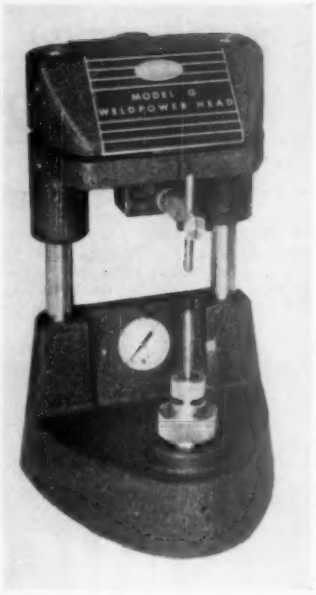
Available in 200, 300, 400 and 500 amp. sizes with stationary or portable mountings, and with a sturdy lifting eye for handling by hoist or crane. Attachments are available for all sizes to adapt these welders for Inert-Gas -Shielded Arc Welding or Inert-Gas-Shielded Spot Welding.

Weldpower Head

A precision-bench mounted spot welder utilizing a new patented idea for obtaining electrode pressures is being manufactured and marketed by Raytheon Mfg. Co., Waltham, Mass.

The Model G Weldpower Head is said to give extremely accurate and consistent electrode pressure through the use of a built-in metallic bellows air-storage system. An air gage in the base of the welder head gives instantaneous indication of electrode pressure and permits rapid adjustment to a predetermined pressure. A small hand pump, available with the equipment, is all that is needed to supply the necessary air pressure.

Another feature claimed for the Model G Weldpower Head is the instantaneous electrode follow-up for forging action due to the extremely low mass (3½ oz.) of the moving parts.



Weldpower head

Bench area required for mounting is only 7 by 7½ in; the unit stands approximately 1 ft. high.

The Model G can be quickly and conveniently converted from precision spot welding to series welding. Complete information may be obtained by writing to the Raytheon Mfg. Co., Dept. 6260NR, Waltham 54, Mass.

Universal Hard-Facing Electrode

For applications where the highest obtainable hardness is desired, Eutectic Welding Alloys Corp., 40 Worth St., New York 13, N. Y. has designed EutecTrode 10, it deposits a bead having a hardness of Rockwell C 63-68. Recommended for use by all those who have wear problems—almost every machine shop, large or small.

Particularly well suited to the hard facing of roller cams, rolling dies, pulverizing rollers and similar items, EutecTrode 10 is most satisfactory because of its high resistance to abrasion. It will withstand the severest operating conditions without appreciable wear, and will extend the useful service life of such equipment for beyond original expectations.

This new electrode combines ease of application with satisfactory weldability. This a.c.-d.c. electrode will not become soft or lose strength at these higher temperatures, and its "red hardness" is far above that of most conventional alloys.

EutecTrode 10 gives smooth dense deposits of excellent corrosion resistance, is available in 1/16, 5/32, and 3/16 in. diameter rods. It will hard surface gray cast iron, steel, high-speed steel and malleable cast iron.

This Lukens man *knows*...

Use "140" MONEL electrodes for welding the clad side of Lukens Monel-Clad Steel

"When customers ask us to recommend a welding rod for the clad side of our Monel-Clad Steel, we tell them to use the new '140' Monel electrode."

These are the words of Mr. L. W. Williams, Manager, Technical Service, Lukens Steel Company, Coatesville, Pa. Mr. Williams' expert advice on metal problems is sought by many users of his company's products.

In explaining his reasons for recommending "140" Monel® electrodes, Mr. Williams said:

"The '140' Monel electrode was especially designed to lay its deposit directly on steel. Since the ductility of the deposit, arcing characteristics and slag removal are unaffected by steel pick-up, there is no need for the customary barrier layer of Nickel.

"Moreover, we know that the customer can be sure the welds he makes with the '140' Monel electrode will meet various code requirements and pass X-ray inspection."

EMBLEM OF SERVICE
INCO
TRADE MARK

In addition to welding the clad side of Lukens Monel-Clad Steel, "140" Monel electrodes give good results in any Monel welding application where steel is present... making Monel overlays on steel, joining Monel to steel or stainless steel.

"140" Monel electrodes are available in standard diameters of 3/32", 5/32", and 3/16". Current requirements are – D.C., reversed polarity.

For additional information about the welding of Inco Nickel Alloys, write for: *Bulletin T-2, "The Welding, Brazing, and Soldering of Monel, Nickel, and Inconel."*

NOW—FOR YOUR CONVENIENCE—Inco welding electrodes are now supplied in new containers... easier to open, better protection during shipping and storage.

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street, New York 5, N. Y.

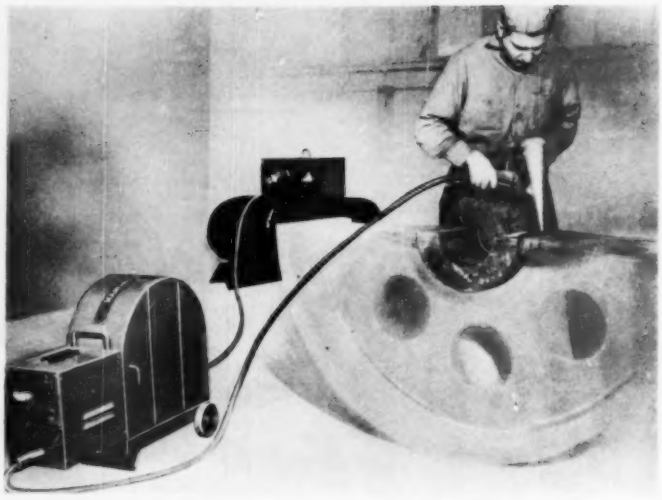
New "Hidensity" Hidden Arc-Welding Process

A new welding process employs welding-current densities on $^{5}/_{64}$-in. electrode wire which melt the electrode at speeds comparable to using 10,000 amp. on a standard $^{5}/_{16}$-in. diameter coated hand electrode. The new "Hidensity" process can be used with any standard S.A.E. 600 or S.A.E. 900 welding generator or an S.A.E. 600 gasoline engine-driven generator.

The new process uses either a $^{3}/_{32}$ or a $^{5}/_{64}$-in. diameter electrode wire. Welding currents up to 600 amp. are used with these wires which, on the small cross-sectional area of the wire, produce extremely high-current densities. These high densities create a deeply penetrating arc which in turn allows the use of high-welding speeds. This also means that in general little or no edge preparation of joints is required, and therefore less weld metal is used in completely fusing the joint.

A "Manual Lincolnweld ML-2" unit for using the "Hidensity" process is connected in a few minutes to any standard S.A.E. 600- or 900-amp. welding generator. This unit provides all the features of an automatic head and is completely self-contained so that it can be moved to the work independently of the welding generator. It can be operated any practical distance from the generator, and because of its flexibility and portability, it can be used on all types of flat and near flat work.

The "ML-2" unit consists of a control case, wire reel case, conductor cable and welding gun. The control case contains a wire feed mechanism, consisting of a variable speed direct-current motor geared to drive rolls, plus an on-off switch, inch button, arc voltage rheostat and current relay. The wire reel case is connected directly to the control case but may be separated from the controls for special applications. Coils of wire are centered at all times on the reel, which is easily removed for loading.



The feed mechanism automatically feeds wire at a preset arc voltage from the reel through the conductor cable to the welding gun. It is fed through the gun to the work. The gun holds inorganic granular flux which is deposited around the high-density arc, completely covering the arc and crater

All WELDING roads lead to the WELDING HANDBOOK

Third Edition

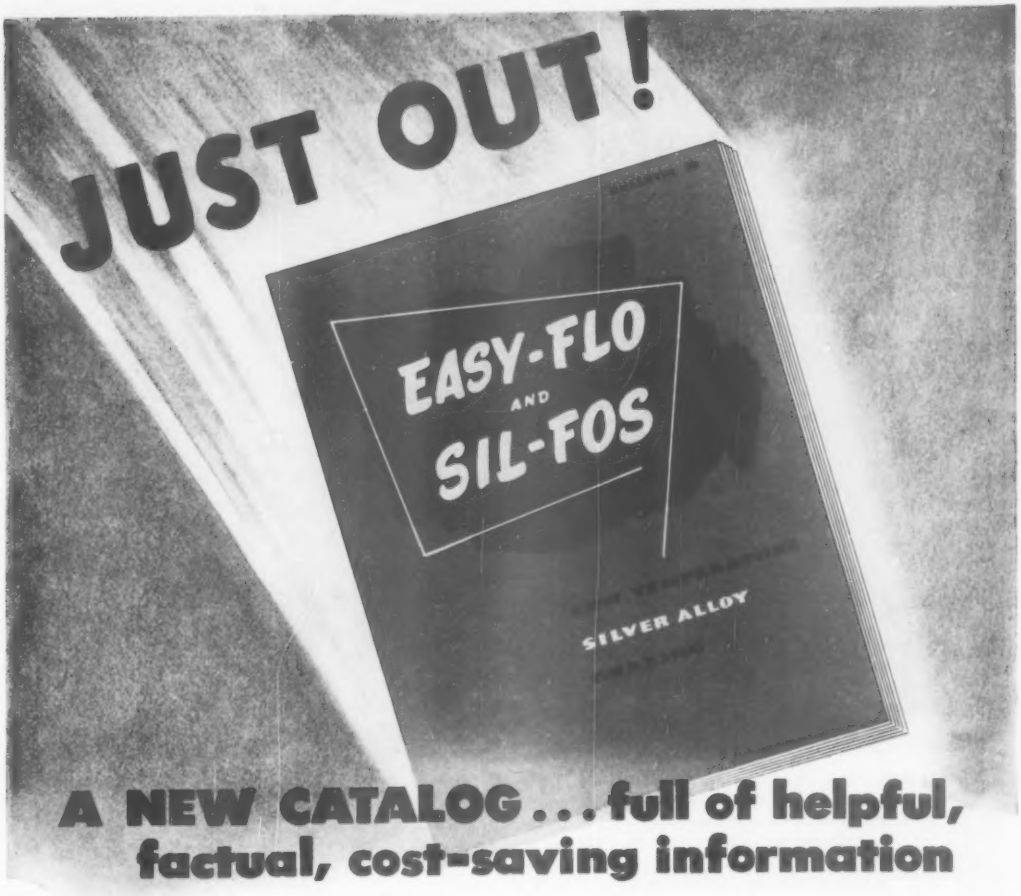
The most complete and authoritative book on every scientific, technical, and practical phase of welding. Covers every process, every metal, all common applications.

1651 pages—more than 300 tables
cloth bound—69-page index
1000 illustrations

ORDER YOUR COPY NOW!

$12 per copy in the U. S. and Canada
$13 elsewhere; $9 per copy to members

AMERICAN WELDING SOCIETY
33 West 39th Street, New York 18, N. Y.



A NEW CATALOG . . . full of helpful, factual, cost-saving information

AT THE CHICAGO METAL SHOW
OCTOBER 23-27

SEE EASY-FLO and SIL-FOS brazing demonstrations and an actual production brazing job in action—also examples of work from many industries. Come in and talk over your metal joining problems with our experienced engineers. Pick up a copy of the new Bulletin 20.

BOOTH 1606

■ It's a storehouse of facts and data — 28 pages of useful information by the originators of *EASY-FLO* and *SIL-FOS*. Tells WHERE and HOW to use these silver brazing alloys to the best advantage; shows many time-tested applications; describes fast brazing techniques; tells how you can speed up production and *save*. It's a "must" for all who design or produce metal assemblies.

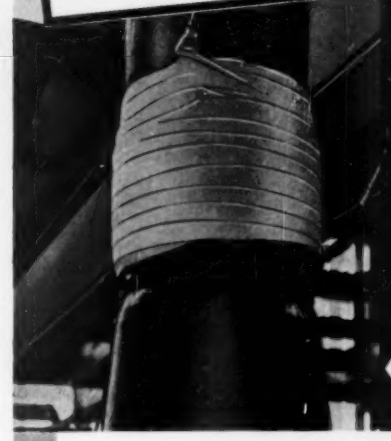
WRITE FOR YOUR FREE COPY TODAY
ASK FOR BULLETIN 20

HANDY & HARMAN

82 FULTON STREET NEW YORK 7, N. Y.

Bridgeport, Conn. • Chicago, Ill. • Los Angeles, Cal. • Providence, R. I. • Toronto, Canada
Agents in Principal Cities

HOW WOULD YOU HEAT A HIGH PRESSURE WELDED PIPE JOINT TO 1700° F. 30 FEET UP IN THE AIR?

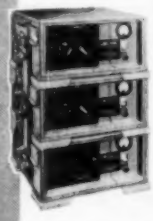


Do It With

Smith-Dolan Preheating Stress Relieving and Normalizing Equipment-By-Induction-Heating at Low Frequencies.

Welded Joint in 20" O.D. — 1 3/8" Wall Carbon Moly Boiler Dawn-Comer Partially Wrapped for Stress Relieving.

- **Smith-Dolan Heating Apparatus can be easily and safely handled by regular job personnel.**
- **It will deliver consistently perfect results under safe conditions assuring minimum job costs.**
- **Thorough heating of heavy wall metal sections can be achieved in a minimum of time with precise control.**
- **Proper heating is delivered according to set specifications and requirements of the Boiler and Piping codes.**



***NEW MODEL U-P** — Patented Smith-Dolan System, portable, low frequency induction heater, three-high stack (shown) 30 kva, 10 kva per unit. Buy one or stack two or three for increased capacity. Buy what you need; build as you go.*

***AUTOMATIC CONTROL CABINET** used with Model U-P units (shown) and Model GC Duplex 120 or 150 kva induction heaters (shown in catalog).*

Electric Arc equipment can be rented or purchased for any job requiring preheating and stress relieving for welding and normalizing.

Write for Informative Catalog

ELECTRIC-ARC INC.

ELECTRIC-ARC, INC.

161 JELLIFF AVE., NEWARK 8, N. J.

AC & DC Welding Equipment • Spot Welder Electrodes & Supplies

as the gun is moved over the joint being welded. The welding gun is moved either by hand or by attaching it to a mechanized carriage of the cutting-torch type.

With the "ML-2" unit connected, a welding generator can be used for either "Hidensity" hidden arc welding or regular "open arc" hand welding; but not at the same time. The same welding machine can be used on a job for regular tack welding and finish welding with the "Hidensity" process.

Colmonoy Nicrobraz

Nicrobraz is a heat and corrosion-resistant alloy for brazing stainless steels. This new material is a stainless type that may well revolutionize many phases of the brazing industry. The joint of a stainless steel assembly brazed with Nicrobraz possesses equal strength at 2000° F. plus better corrosion and oxidation resistance than the parent metal.

Nicrobraz can be used to braze 300 and 400 series stainless steel, Inconel, S-590, Monel, alloy steels, tool steels, carbon steels and special stainless steels. An assembly to be brazed with Nicrobraz is prepared the same as for copper brazing. It has been found that the joint clearance should not be over 0.002 in. where highest quality joints are desired. As stainless steels oxidize in regular brazing furnace atmospheres, brazing is best accomplished in pure dry hydrogen of −40° F. dew point or below. Nicrobraz is applied to the part and is held in place with Nicrobraz Cement and it will flow throughout a joint by capillary action when heated to 2050° F.

After 510 hr. at 1600° F. in an air atmosphere the Nicrobraz joint shows no signs of oxidation and no loss of tensile strength.

The physical properties of Nicrobraz leave no question as to its suitability for Jet Engines. New designs have been opened up in this field due to its remarkable high temperature properties.

In other commercial fields, such as: food, dairy, beverage, chemical, mercury, nuclear energy, automotive, oil refinery and medical, there are vast possibilities.

Nicrobraz is available as a powder in one-pound containers. It is priced less than silver-brazing alloys. Nicrobraz Cement comes in pint containers.

Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich., offers engineering assistance for stainless-steel brazing development work.

Whether you fabricate machinery, tanks, containers or structural members, Lincoln's

NEW High-Current-Density

HIDDEN-ARC WELDING PROCESS

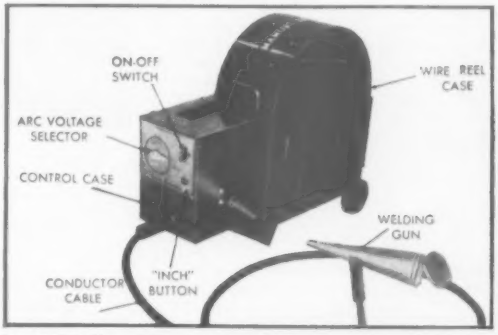
can cut your welding costs

Here's the latest, most important development in faster, easier, lower-cost arc welding... Lincoln's exclusive High-Current-Density, Hidden-Arc Welding Process. Through the use of current densities up to 600 amps. on ¼" diameter continuous welding wire (equivalent to 9600 amps. on a ⅛" rod!) you get welding speeds up to 360 inches per minute . . . *3 to 4 times that possible with conventional hand welding.*

Now with the new "Manual Lincolnweld ML-2" the effective cost-cutting benefits of deeper penetration and higher-quality welding in granular flux are further extended to an even wider range of work. With its compact, portable design, the new "Manual Lincolnweld" can be speedily moved to any part of the shop to simplify welding on all flat or near-flat work. It operates from any Lincoln 600 or 900 amp. "Shield-Arc" motor driven or 600 amp. engine driven arc welder, further making it easy to move about the shop especially in confined areas.

For additional flexibility, the welding gun, which uses either ¾" or ⅜" wire, can be hand-held or mounted in a simple fixture. The unit can be set also for either "Manual Lincolnwelding" or normal hand welding with coated electrodes.

The High-Current-Density, Hidden-Arc Welding Process is an exclusive process of The Lincoln Electric Company, Cleveland, Ohio.



New "ML-2 Manual Lincolnweld" Weight without wire reel only 121 pounds. The control case alone weighs only 50 pounds and can be detached from wire reel case for additional portability in restricted spaces.

GET THE FACTS

Send for free "Manual Lincolnweld" Bulletin 1303, write

THE LINCOLN ELECTRIC COMPANY

Dept. 99, Cleveland 1, Ohio

Sales Offices and Field Service Shops In All Principal Cities

LINCOLN

Safety Shield

Fabricated from hardware cloth and high-grade canvas, treated according to U. S. Spec. CCC-D-746, a new cloth safety shield, "Spa-Fla," protects property and personnel in the work area from sparks, hot chips and flying particles and guards against eye burns from flash.

The safety shield will stand by itself, formed in any position, around the job being performed—welding, flame cutting, grinding and as a wind-break or sun-shade on outside work. Easels may be attached for field work or to ventilate inside jobs.

"Spa-Fla," distributed by Safety First Supply Co., Pittsburgh, Pa., can be rolled compactly and carried easily from job to job by one man. It is stocked in two sizes, 48 in. x 72 in. and 36 in. x 72 in., or it can be made up to any size.

Nonferrous Metals Now Preclad with Silver-Brazing Alloy

Most nonferrous metals can now be obtained in strip form, clad on one or both sides with a layer of silver-brazing alloy.

This development, known as Braze-clad, consists of laminating a layer of silver-brazing alloy to one or both sides of such metals as copper, most types of brass, all types of nickel silver, jewelers' bronze, beryllium copper, cupro-nickel, nickel, monel, etc. This clad preplacement of the silver-brazing alloy will result in tremendous savings in time and labor throughout the metal-working industry.

In the Braze-clad process, the silver-brazing alloy is diffused into the parent metal at the supplier's plant and can be of any specified thickness and in any commercial melting range. Braze-cladding eliminates the necessity of using rings, washers, preformed special shapes and other forms of silver-brazing alloy currently used in metal joining. Since the entire joint surface of the parent metal is prediffused with silver-brazing alloy, voids caused by dry spots and oxide islands are eliminated. Longer and more uniform joints are possible than when face feeding is employed or where distribution of the alloy is dependent upon capillary creep.

Braze-clad metals can be blanked, stamped and drawn in the usual manner, whether clad on one side, both sides or in inlaid stripes. Being extremely ductile, the brazing alloy follows the contours of the forming dies, yet presents a specified bonding thickness at all times.

Multiple joining, as performed by "induction heating" or furnace brazing, can be accomplished simply by placing the parts to be joined in the proper position, fluxing and heating in the usual manner.

Typical applications of Braze-clad metals include hollow handles for cutlery and silverware, cap-on-rod joints, hidden joints, seamed tubes and the joining of irregularly shaped parts, springs, studs, contact arms, etc.

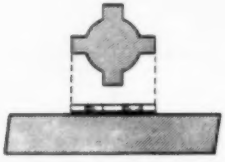
Braze-clad nonferrous metal strip is made by the Rolled Plate Division of the American Silver Co., Inc., Flushing, N. Y.

Portable Ultraviolet Light Source

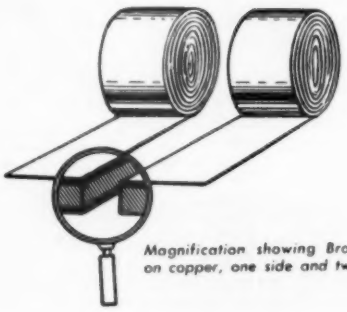
For the nondestructive testing of structures, weldments, vessels and other objects too large for transport to a permanently-installed black-light booth, the new Menlo Fluoretor combines portability and self-powered operation with facilities to permit observation under the most intense ambient light. Total weight of the operating unit is less than 2 lb.

Two standard Size D flashlight bat-

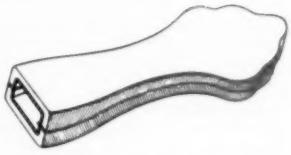
Portable Ultraviolet Light Source



Irregular shaped joint made from Braze-Clad brass eliminates special blanking of silver brazing alloy



Magnification showing Braze-Clad on copper, one side and two sides



Braze-Clad insures perfect joints on knife handles and other shell-like parts

THESE NICKEL STEEL ELECTRODES

Assure tough welds... even in frigid weather

Try 2¼-3½% nickel steel electrodes and see how easily you complete strong, tough, sound welds . . .

Porosity, cracking, and brittleness, even at low temperatures can be avoided when you use these nickel steel arc welding electrodes. Coatings are of the low-hydrogen-type.

Examine the test data. Look at the charts to determine the excellent properties offered by these tough nickel steel welding electrodes.

Applications include use on railroad equipment, on power shovels and all types of earth-moving machinery, on heavy-duty truck bodies and similar types of structures fabricated from wrought and cast steels.

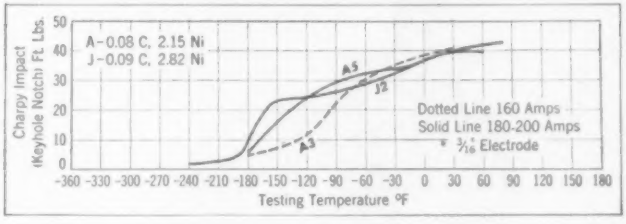
Write today for list of sources from which you can obtain these electrodes.

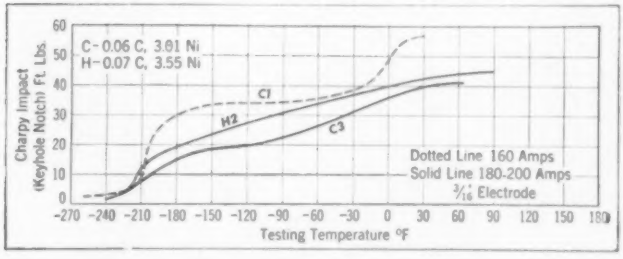
%Ni	Yield Strength psi.	Tensile Strength psi.	Elongation in 2 in. %	Reduction of area. %	Condition
2¼	76,250	91,750	22.5	62.7	A.W.*
3	73,100	87,250	29.0	71.4	A.W.
2¾	69,350	90,500	25.0	59.7	A.W.
3½	75,000	89,250	26.0	61.5	S.R.**

*As welded. **Stress relieved at 1150°F

"Tensile Test Data on All-Deposited Metal from 3/16" Nickel Steel Electrodes."

Effect of temperature on impact properties of weld metal containing *less* than 3% nickel.





Effect of temperature on properties of weld metal containing *more* than 3% nickel.

EMBLEM OF INCO SERVICE

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

teries supply power for the ultraviolet generator which is attached by a swivel joint to the wand-type handle containing power components. A light-tight dark chamber fits around the generator head to exclude light from the area under examination. A sponge-rubber cone improves the light seal on rough or irregular surfaces. A series of specimen-holding end caps fits the mouth of the dark chamber so small objects can be examined without removing them to a darkened area. A focussing eyepiece provides 3 times magnification for the observer.

Alternative generator-filter heads are available for operation at either 2537 or 3660 Angstroms. Due to the swivel arrangement and the slip fit of the dark chamber, the unit can be set to the most convenient viewing position for right- or left-handed; right- or left-eyed use. Menlo Research Laboratory, P. O. Box 522 CT, Menlo Park, Calif.

Low-Priced Portable Magnaflux Unit

A new, portable and general purpose Magnaflux Unit is announced, which is expected to find wide application for maintenance inspection, safety inspection and for wide application in general inspection. The low price of $485 is a complete price, which entitles the purchaser to a day of instruction in magnetic particle inspection, at no further cost. With Magnaflux, all defects such as invisible fatigue cracks, shrink cracks, weld cracks, etc., are made readily visible by a magnetic particle indication built up on them by quick magnetization. The training of a maintenance man or inspector is carried out by a Magnaflux Field Engineer, based upon twenty years work with magnetic particle inspection in all types of manufacture and overhaul.

The KH-05 Magnaflux Unit is developed to furnish the best on-the-job inspection. It requires only 110-v a.c. supply line to give a.-c. or d.-c. magnetization with safety and flexibility, using low voltage, high-amperage magnetizing currents. 500 magnetizing amperes are available.

Magnaflux Corp., 5900 Northwest Highway, Chicago 31, Ill.

Torch Holder

The Krohn Mfg. and Supply Co., Centreville, Mich., announce the new "Krohn Star" Pantograph Torch Holder for contour flame cutting and butt welding.

The machine operates on the principle of the pantograph which assures accurately cut patterns, devoid of ragged edges. Besides making flame cutting easier and more accurate, the "Krohn Star" torch holder lessens eye strain as the operator is stationed several feet from the flame and he does not need to watch it steadily.

This machine can be used to good advantage by the small commercial shops, trade schools, high school and college industrial arts shops, hobbyists and by large plants for the smaller jobs that do not justify using the elaborate electrically operated flame cutters. By substituting a welding torch for the cutting torch, light materials can be butt welded.

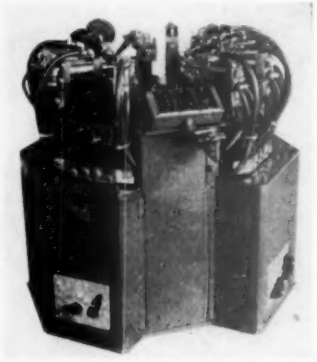
The "Star" cuts circles or rings up to 24 in. in diameter, a straight cut 52 in. long, also squares and combinations of curves and angles.

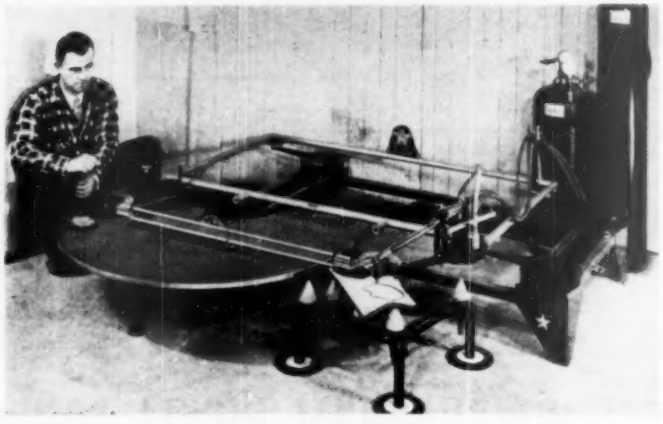
Adjustable templates or form duplicators are furnished with the machine and others can be cut from light metal with a pair of tin snips. Thus the contour template problem is simplified.

The arm which holds the torch is adjustable to fit various types of hand and machine torches. The workpiece stand is adjustable for different thicknesses of steel without changing the supports. For very large sheets of steel additional workpiece stands or posts are supplied. The heart-shaped operating table may be attached to either the right or left end of the machine. The operating arms are also interchangeable, and the steel workpiece stand may be moved as desired.

Welding Household Mixer-Base Units

The machine is basically a table-top welder with ten adjustable self-centering welding guns and five series welding transformers rated 35 kva. at 50% duty cycle. An electronic control cabinet (not shown) is mounted separately and has a control sequence of Squeeze-Weld-Hold-and-Off Times. In actual operation the operator places the parts to be welded in their respective locations on the welder and after depressing a control button, initiates the welding cycle which completes all ten welds in one operation. This machine can weld better than 520 units per hour as compared with 125 units formerly produced on a foot-operated welder. No buffing or grinding is necessary on the completed parts. By simple adjustment of the locating fixtures and repositioning the welding guns, various size and shape bases can easily be loaded and welded in one operation.





Torch Holder

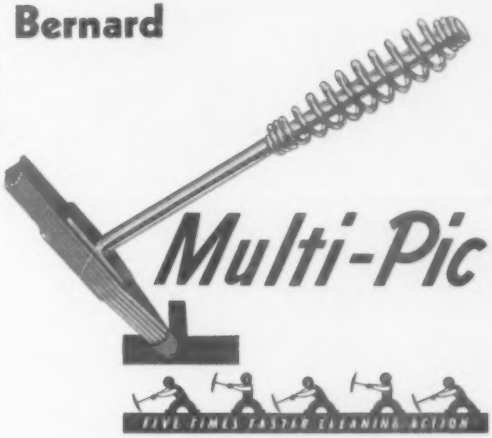
Outstanding Bernard Welding Products

Bernard

"Shortstub"

Reduces electrode stub waste by depositing the total fluxed length of every electrode—remains *comfortably cool* even under continuous operation. Two sizes: 400 amp. and 600 amp.

Bernard



Multi-Pic

Five "full floating" individual heads, precision hardened, conform perfectly to concave, convex or irregular surfaces. Metal or wood handles, with or without wear-compensating "Repeater" brushes.

Bernard

"Pro-Clamp"

The fastest and most accurate method of positioning and holding plates, structural shapes, pipe, etc. Reduces a former two-man operation to a one-man job! The *only* tool of its kind!

and now . . .

watch
for our
announcement
of the
new

Bernard

"Seam-Liner"

The new 60 second tool for lining up and fitting butt, lap and other joints.

Manufactured by **BERNARD WELDING EQUIPMENT CO.,** 741 EAST 71st STREET CHICAGO 19, ILLINOIS

NEW Aircomatic® Process jumps Welding Speeds to NEW HIGHS

Aircomatic is a new metal arc welding process that permits high-speed welding of aluminum, of aluminum bronze and of stainless steel – *in all positions*..

The process uses a bare wire electrode in coil form, continuously fed to the work within an inert gas shield. High current densities are used providing excellent penetration and high deposition rates, *permitting welding at speeds greater than ever before possible.*

Aircomatic welding has proved most economical . . . for its high deposition rate, in addition to permitting high travel speed, also makes possible fewer passes on heavy material, and faster, heavier deposits for overlay or build-up work. This means more weld per unit of arc time, whatever the job. Further, since the wire is bare and continuously fed through a shield of inert gas, electrode changes and slag removal interruptions are eliminated, thus permitting almost 100% arc time in using the high operating speeds.

SAVES 16 MAN-HOURS WELDING TIME . . . Dempster Brothers, Incorporated of Knoxville, Tenn., makers of the nationally-known "Dempster-Dumpster" found Aircomatic welding cut their aluminum container manufacturing costs.

The other method was slow – cumbersome, and ran the cost exceedingly high. With Aircomatic the same container was produced – at a welding cost reduction of approximately 16 man-hours.

Another important feature of Aircomatic welding is its minimization of distortion. This is due to its high speed operation (heat can be concentrated and moved rapidly along the work), plus the fact that a small amount of weld metal is all that's required in most joints.

The case studies on the opposite page show how this dramatic new welding process is helping others. While the facts and figures are startling, they could very easily be applied in your own shop . . . but find out for sure. Write . . . or phone your nearby Airco office. Ask for a copy of ADR 66: "Aircomatic Welding Process".

SAVES 4½ HOURS . . . Martin-Quaid Co., of Philadelphia, Pa., used the New Aircomatic Process to reduce the time and cost of welding huge stainless steel cylinders used in the manufacture of carpets. They found this revolutionary process cut materials cost 25% . . . and saved 4½ hours working time over the old method — and, at the same time, greatly increased the quality of the finished product.

REDUCES TIME 4/5's . . . Consolidated Welding and Engineering Company, of Chicago, Ill., adopted the new Aircomatic process for welding aluminum separators. Immediately, major production and cost problems were solved: To weld one complete separator assembly took only 90 man hours — about 1/5 the time of other methods.

Further, Aircomatic's high current density and the attendant high welding speed confined the heating effects to the narrow weld-zone . . . completely eliminating distortion.

ELIMINATES LEAKS . . . Griffin & Company, of Louisville, Ky., found Aircomatic's high speed and the ability to make welds without interruption ideally suited to the fabrication of tanks for all-aluminum evaporative coolers. Production time and cost was cut to the minimum, and warpage and distortion were completely eliminated. Thus far, the company has made hundreds of these tanks without a single leak.

BOOSTS PRODUCTION 71% . . . The Stewart-Warner Corporation, South Wind Division, Indianapolis, Ind., join the upper and lower halves of its "Safe-Air Gas Home Heater" with the completely new, high-speed Aircomatic Process. This time-saving, cost-cutting process skyrocketed production 71% . . . and cut manufacturing costs in proportion.

See Aircomatic in Operation at our Booth—No. 422 • Chicago National Metal Show October 23-27, 1950.

AIRCO **AIR REDUCTION**

Offices in Principal Cities

HEADQUARTERS FOR OXYGEN, ACETYLENE AND OTHER GASES . . . CALCIUM CARBIDE . . . GAS CUTTING MACHINES . . . GAS WELDING AND CUTTING APPARATUS, AND SUPPLIES . . . ARC WELDERS, ELECTRODES AND ACCESSORIES

SECTION ACTIVITIES

prepared by C. M. O'Leary

Birmingham

The following are the officers and chairmen of committees elected for the fiscal year by the Birmingham Section: *Chairman*—Alfred E. Pearson, Ingalls Iron Works Co.; *1st Vice-Chairman*—D. H. Curry, Chicago Bridge & Iron Co.; *Secretary-Treasurer*—E. D. McCauley, American Cast Iron Pipe Co.; *Chairman, Membership Committee*—W. B. Browning; *Chairman, Program Committee*—J. Thompson Vann and *Technical Representative*—John E. Durstine, Lincoln Electric Co.

Cleveland

The following officers and chairmen of committees have been elected by the Cleveland Section for the fiscal year: *Chairman*—J. C. Wyss; *1st Vice-Chairman*—F. G. Flocke; *2nd Vice-Chairman*—J. J. Jarms; *Secretary-Treasurer*—J. F. Wagner; *Chairman, Membership Committee*—W. F. Stewart; *Chairman, Program Committee*—F. G. Flocke, Technical Program, J. J. Jarms, Symposium Program and H. A. Hallstein, Coffee Program and *Technical Representative*—K. C. Thornton.

Columbus

The following is the program of meetings arranged by the officers of the Columbus Section for the 1950–51 season.

Oct. 13th—Plant Visit—Cooper-Bessemer Corp., Mount Vernon, Ohio. Speaker, R. F. Kymer, Engineer, Cooper-Bessemer Corp. Subject, "Cost of Casting versus Fabrication."

Nov. 10th—Student Section Meeting—O.S.U., Columbus, Ohio. Speaker, V. A. Henry, Bendix Prod. Div., Bendix Aviation. Subject, "Welding Zinc-Based Die Castings," South Bend, Ind.

Dec. 8th—Fort Hayes Hotel. Speaker, E. B. Lutes, Welding Engr., Arcrods Corp., Sparrows Point, Md. Subject, "Arc-Welding Electrode."

Jan. 12th—Fort Hayes Hotel. Speaker, Howard S. Avery, Research Met., American Brake Shoe, Mahwah, N. J. Subject, "Hard-Surfacing."

Feb. 9th—A.S.M.—Joint Meeting—Fort Hayes Hotel. Speaker, Dr. M. Gensamer, Carnegie-Illinois Steel, Pittsburgh, Pa. Subject, "Steel Under Stress."

Mar. 9th—Fort Hayes Hotel. Speaker, Paul H. Setzler, Lima-Hamilton Corp., Hamilton, Ohio. Subject, "Stress Risers as They Affect Welded Design."

Apr. 13th—O.S.U. Conference.

May 11th—Annual Meeting.

Detroit

The following officers and chairmen of committees have been elected by the Detroit Section for the fiscal year: *Chairman*—E. B. Brown; *1st Vice-Chairman*—Keith Sheren; *2nd Vice-Chairman*—A. E. Lindsey, Ford Motor Co.; *Secretary-Treasurer*—J. R. Stitt; *Asst. Secy.*—J. M. Johnston, The Murray Corp. of America; *Chairman, Membership Committee*—B. R. Hawks, Ace Welding Supply, Inc.; *Chairman, Program Committee*—Keith Sheren and *Technical Representative*—A. C. Good, Wayne University.

Los Angeles

The following officers and chairmen of committees have been elected by the Los Angeles Section for the fiscal year: *Chairman*—Charles Schweitzer; *1st Vice-Chairman*—C. W. Johnson; *Secretary-Treasurer*—Herbert Clemens, C. F. Braun & Co.; *Chairman, Membership Committee*—A. K. Brumbaugh, Jr.; *Chairman, Program Committee*—C. W. Johnston and *Technical Representative*—C. W. Johnston.

Mahoning Valley

The following officers and chairmen of committees have been elected by the Mahoning Valley for the fiscal year: *Chairman*—Harry E. Lyon; *1st Vice-Chairman*—W. G. Dixon, American Welding & Mfg. Co. and *Secretary-Treasurer*—O. H. Kuhlke, General American Transportation.

Maryland

The following officers and chairmen of committees have been elected for the fiscal year by the Maryland Section: *Chairman*—G. E. Claussen, Reid-Avery Co.; *1st Vice-Chairman*—Fritz Albrecht; *Secretary*—Aldridge L. Lees; *Chairman, Membership Committee*—Frederick E. Bryant; *Chairman, Program Committee*—Fritz Albrecht and *Technical Representative*—Prof. T. B. Jones, The Johns Hopkins University.

Cumberland Valley Division of Maryland Section

The following officers and chairmen of committees have been elected by the Cumberland Valley Division for the fiscal year: *Chairman*—B. E. Wingert; *1st Vice-Chairman*—R. F. Baughman; *Secretary*—J. E. Brenner; *Treasurer*—C. L. Snyder; *Chairman, Membership Committee*—F. S. Barnitz; *Chairman, Program Committee*—Charles R. Berry and *Technical Representative*—J. F. Caughlan.

Milwaukee

The following officers and chairmen of committees have been elected by the Milwaukee Section for the fiscal year: *Chairman*—G. W. Peupold; *1st Vice-Chairman*—R. P. Walbridge; *Secretary-Treasurer*—Frank Harencki; *Chairman, Membership Committee*—Donald G. Wilson; *Chairman, Program Committee*—R. P. Walbridge and *Technical Representative*—L. E. Grant.

New Jersey

The following officers and chairmen of committees have been elected by the New Jersey Section for the fiscal year: *Chairman*—Walter Begerow, Air Reduction Sales Co.; *1st Vice-Chairman*—Frank Yurasko, Standard Oil Development Co.; *Secretary-Treasurer*—P. M. Mattern, Wilson Welder Co.; *Chairman, Membership Committee*—John E. Gunning, Electric Arc, Inc.; *Chairman, Program Committee*—Ken Koopman, The Linde Air Products Co. and *Technical Representative*—F. C. Fyke, Standard Oil Development Co.

Northwest

The following officers and chairmen of committees have been elected by the Northwest Section for the fiscal year: *Chairman*—Dr. F. W. Scott, Marquette Mfg. Co.; *1st Vice-Chairman*—E. L. Hixson, Minneapolis-Moline Co.; *Secretary-Treasurer*—Lillian K. Polzin, Minneapolis Chamber of Commerce; *Chairman, Membership Committee*—Marshall H. Ford, Lincoln Electric Co.; *Chairman, Program Committee*—E. L. Hixson and *Technical Representative*—E. L. Hixson.

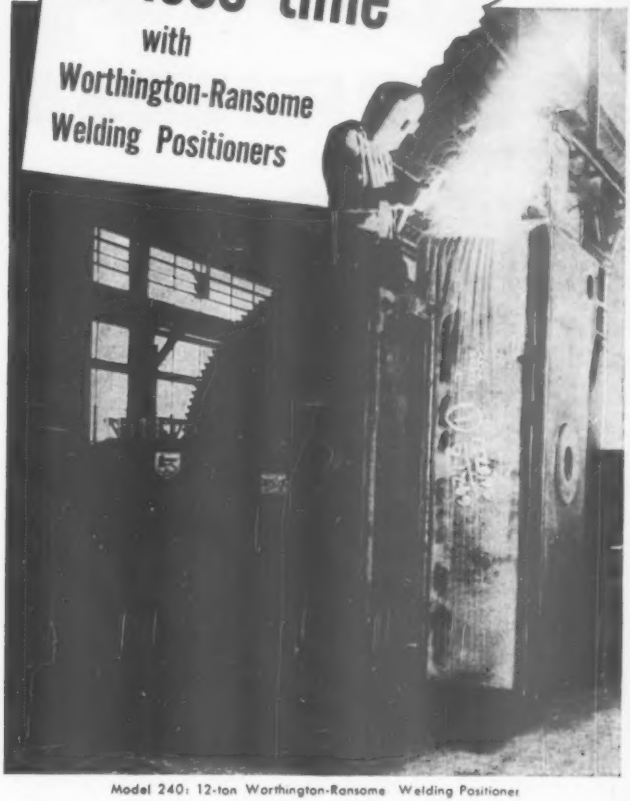
Northwestern Pennsylvania

The following officers and chairmen of committees have been elected by the Northwestern Pennsylvania Section for the fiscal year: *Chairman*—Ed J. Brown, Erie, Pa.; *1st Vice-Chairman*—Fred T. Perry, Erie, Pa.; *Secretary-Treasurer*—W. R. Boyd, Erie, Pa.; *Chairman, Membership Committee*—Robert J. Huston, Jr., Erie, Pa.; *Chairman, Program Committee*—Fred T. Perry and *Technical Representative*—Robert K. Allen, Wesleyville, Pa.

Oklahoma City

The following officers and chairmen of committees have been elected by the Oklahoma City Section for the fiscal year:

These Welders Produce more in less time with Worthington-Ransome Welding Positioners



Model 240: 12-ton Worthington-Ransome Welding Positioner

One sure way to drive production costs down and meet competitive prices is to have a Worthington-Ransome positioner "handle" the work. Your welder can then get more *arc time* out of each working hour.

All welds, either manual or automatic, can be made in the economical "downhand" position, using heavier electrodes, for better, neater, quicker welds.

The full line of Worthington-Ransome positioning equipment includes Positioners with capacities from 100 lbs to 20 tons; and Turning Rolls with capacities from 3 tons to 75 tons, both stationary and self-propelled.

Model 5: 500 lb Worthington-Ransome Welding Positioner

Model 1P: 100 lb Worthington-Ransome Welding Positioner

Model 400: 20-ton Worthington-Ransome Welding Positioner

WORTHINGTON

WORTHINGTON PUMP AND MACHINERY CORPORATION

Welding and Assembly Positioning Equipment Division

DUNELLEN, NEW JERSEY

Worthington Pump and Machinery Corp.
Dunellen, N. J.

Please send Bulletin 210C on Worthington Ransome Welding Positioners.

NAME .....

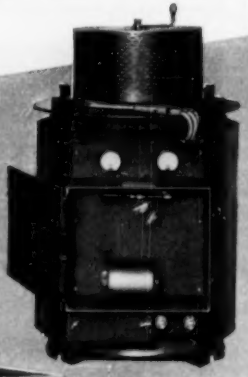
COMPANY .....

ADDRESS .....

A pioneer in the development of a-c welding since 1919, G.E. is constantly improving the performance of its welders . . . and has **STEADILY REDUCED PRICES!**

1934

With the development of coated electrodes, the use of a-c welders commercially became a reality. This 1934 500-amp model weighed about 1200 pounds and was sold for $825.



1937

This a-c welder, also 500-amps, tipped the scales at 900 pounds. It was sold for $675.

1940

With this 300-amp welder, weight was cut to 600 pounds and it was sold for $530.

1949

By 1949 the 500-amp welder was streamlined and was sold for $495.

New FOR LESS

40"

1940 **This standard 300-amp a-c welder, though not big for its day, was unwieldy and cumbersome compared to today's compact models. It weighed 600 pounds and sold for $410.**

1950 G-E welders give you—

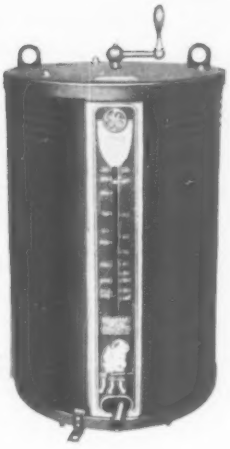
1. *Automatic "Hot-Start" Control*—easy arc-striking with *no* manual adjustment necessary.
2. *Arc-Stabilizing Capacitors*—assure a steady arc with no pop-outs.
3. *G-E Silicone Insulation*—Use of *SILICONE* insulation results in a lightweight, space-saving welder. Since this insulation is water-repellent and resistant to high temperatures, it offers maximum protection for both operator and welder.
4. *Stepless Current Control*—gives you precise current settings over the entire wide range.
5. *Built-in Capacitors*—reduce input current and improve power factor, reducing installation and power costs.
6. *Fan-forced Ventilation* (in 400-amp ratings and larger)—maintains cool, safe operating temperatures.

You can put your confidence in . . .

A-C Welders

THAN 1940 PRICES

35"



Today's G-E Welders give you 6 Major Improvements for Less Money

1950 Including many new features, which mean superior performance, this latest Type WK-30 welder weighs just 328 pounds and is sold for $310*—a reduction of 272 pounds and $100.

Yes, General Electric welder design, performance, and appearance have been continually improved. With all of these improvements at less than pre-war prices, you just can't lose with a 1950 General Electric welder. Consult your nearest G-E Welding Distributor to determine the type and rating of welder best suited to your requirements; he can give you immediate delivery on all standard models. If you don't know him, write us for his name and address: *Apparatus Department, General Electric Company, Schenectady 5, N. Y.*

*Prices are manufacturer's suggested retail price in Zone 1. Slightly higher in other zones.

200-AMP WELDERS, TOO . . .

Weighs only 154 lbs.

Less than two feet high, this welder includes all of the money-saving features of the standard G-E 300-amp a-c welder. With a current range from 30 to 250-amps and NEMA rated at 50% duty cycle, it can weld many a job without having to tie up large units.

ARC-WELDERS • ELECTRODES • ACCESSORIES • RENEWAL PARTS

GENERAL ELECTRIC

Chairman—Bill Gleason; *1st Vice-Chairman*—R. O. Jackson; *2nd Vice-Chairman*—Bill Klein; *Secretary*—L. D. Robson; *Treasurer*—Lon Erickson; *Chairman, Membership Committee*—Bob Hughes and *Chairman, Program Committee*—Bill Littlefield.

Pascagoula

The following officers and chairmen of committees have been elected by the Pascagoula Section for the fiscal year: *Chairman*—John F. Bryan, Jr.; *1st Vice-Chairman*—Alexander Mair; *Secretary-Treasurer*—Irwin W. Whittemore; *Chairman, Membership Committee*—John S. Howkins, Jr.; *Chairman, Program Committee*—Thomas J. Dawson and *Technical Representative*—William D. Pelan.

Peoria

The following officers and chairmen of committees have been elected by the Peoria Section for the fiscal year: *Chairman*—D. F. McCowan, Bartonville, Ill.; *1st Vice-Chairman*—M. Packer, Peoria; *Secretary*—K. Purcell, Peoria; *Treasurer*—J. Hanley, Peoria; *Chairman, Membership Committee*—G. Deemy, Peoria and *Chairman, Program Committee*—Donald L. Stine, Peoria.

Pittsburgh

The following officers and chairmen of committees have been elected by the Pittsburgh Section for the fiscal year: *Chairman*—T. W. Morgan, Armco Steel Corp., Butler, Pa.; *1st Vice-Chairman*—E. H. Turnock; *Secretary-Treasurer*—J. F. Minnotte, Minnotte Bros. Co.; *Chairman, Membership Committee*—Chas. J. Burch, The Linde Air Products Co.; *Chairman, Program Committee*—F. H. Dill, American Bridge Co. and *Technical Representative*—H. P. Schane, Mellon Institute of Industrial Research.

Portland

The following officers and chairmen of committees have been elected by the Portland Section for the fiscal year: *Chairman*—Chas. J. Daniels, Beaverton, Ore.; *1st Vice-Chairman*—E. H. Weil, Lincoln Electric Co.; *Secretary*—Raymond L. Howerton, Hyster Co.; *Treasurer*—Stan Richardson, Air Reduction Pacific Co.; *Chairman, Program Committee*—Ed Weil and *Technical Representative*—Leslie Poole.

Puget Sound

The following officers and chairmen of committees have been elected by the Puget Sound Section for the fiscal year: *Chairman*—Alex D. Sweek, Seattle, Wash.; *1st Vice-Chairman*—Wm. Snider, University of Washington and *Secretary-Treasurer*—C. R. Goetjen, Seattle, Wash.

Richmond

The following officers and chairmen of committees have been elected by the Richmond Section for the fiscal year: *Chairman*—Paul Hickman; *1st Vice-Chairman*—Charles L. Williams, Richmond Structural Steel Co.; *2nd Vice-Chairman*—John A. Richman; *Secretary*—C. L. Mitchell, Welders Supply Co.; *Treasurer*—A. A. Adcock, Old Dominion Iron & Steel Corp.; *Chairman, Membership Committee*—Lawrence Thomason, Southern Oxygen Co.; *Chairman, Program Committee*—Frank Cervarich, Capital City Iron Works and *Technical Representative*—Vaughan E. Calder, Jr.

Roanoke

The following officers and chairmen of committees have been elected by the Roanoke Section for the fiscal year: *Chairman*—R. P. Winton, Norfolk & Western Railway Co.; *1st Vice-Chairman*—R. M. Baldock, Norfolk & Western Railway Co.; *2nd Vice-Chairman*—W. E. Rose, Virginia Bridge Co.; *Secretary*—R. W. Fronk, Roanoke Steel & Supply Co.; *Treasurer*—U. N. Brenner, Roanoke Scrap Iron & Metal Co.; *Chairman, Membership Committee*—R. P. Winton; *Chairman, Program Committee*—R. P. Winton and *Technical Representative*—R. M. Baldock.

St. Louis

The following officers and chairmen of committees have been elected by the St. Louis Section for the fiscal year: *Chairman*—R. K. MacIntyre, Shell Oil Co., Wood River, Ill.; *1st Vice-Chairman*—D. Harrelson, Midwest Piping & Supply Co.; *Secretary*—Jack Fox, Machinery & Welder Co.; *Treasurer*—P. W. Salsich, The Linde Air Products Co. and *Technical Representative*—Richard W. Weeks, Shell Oil Co.

Tri-State

The following officers and chairmen of committees have been elected by the Tri-State Section for the fiscal year: *Chairman*—Dana S. Cope, Servel, Inc., Evansville, Ind.; *1st Vice-Chairman*—E. E. Cashen, Evansville, Ind.; *2nd Vice-Chairman*—K. Werling, Evansville, Ind.; *Secretary*—Webb Niekamp, Evansville, Ind. and *Treasurer*—Wilbur Seifert, Evansville, Ind.

Tulsa

The following officers and chairmen of committees have been elected by Tulsa Section for the fiscal year: *Chairman*—F. D. Davenport, Maloney Crawford Co.; *1st Vice-Chairman*—Frank Best, Flint Steel Co.; *Secretary*—L. F. Douglas, General Electric Co.; *Treasurer*—W. A. Emery, Western Supply Co. and *Technical Representative*—John H. Tipton, Maloney Crawford Co.

Washington, D. C.

The following officers and chairmen of committees have been elected by the Washington, D. C. Section for the fiscal year: *Chairman*—E. M. MacCutcheon, Bureau of Ships, U.S.N.; *1st Vice-Chairman*—W. P. Roberts, Southern Oxygen Co.; *Secretary*—Mrs. B. M. McPherson, B. & M. Welding & Iron Works and *Treasurer*—Paul Tarver, Silver Spring, Md.

Western Massachusetts

The following officers and chairmen of committees have been elected by the Western Massachusetts Section for the fiscal year: *Chairman*—Carl A. Keyser, Amherst, Mass.; *1st Vice-Chairman*—Lee Jaeger, Springfield; *Secretary*—Victor L. Bissonnette, Springfield; *Treasurer*—Frank Taft, W. Springfield; *Chairman, Membership Committee*—Frank Taft; *Chairman, Program Committee*—Sidney Low, Indian Orchard and *Technical Representative*—Carl A. Keyser.

Wichita

The new membership chairman for the Wichita Section is E. A. Bussard of Wichita.

York-Central Pa.

The following officers and chairmen of committees have been elected by the York-Central Pa. Section for the fiscal year: *Chairman*—Gus Ostrom, Abbottstown, Pa.; *1st Vice-Chairman*—David F. Walters, York; *Secretary*—Robert Luckenbaugh, York; *Treasurer*—Charles Allen, York and *Technical Representative*—Richard K. Lee, York.

abstracts of CURRENT WELDING PATENTS

Prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commission of Patents, Washington 10, D.C.

2,512,705 — Fluid-Cooled Gas-Blanketed Arc-Welding Torch—Nelson E. Anderson, Scotch Plains, and George R. Turbett, East Orange, N. J., assignors to Air Reduction Co., Inc., a corporation of New York.

2,512,707—Gas-Shielded Arc-Welding Torch—Nelson E. Anderson, Scotch Plains, N. J. assignor to Air Reduction Co., Inc., a corporation of New York.

These patents relate to special electrode holders wherein a collet is supported on a body portion, which collet has an axial opening therein for receiving the electrode and also has resilient electrode-gripping jaws to hold the electrode in coaxial relation with the body portion. A collet sleeve is provided and has threaded connection with the body portion and engages the jaws of the collet to press them against the electrode when the collet sleeve is screwed onto the body portion. The body portion has a collet-receiving socket formed thereon and the collet is removably engaged with the body portion whereby other collets with different internal diameters can be engaged with the body portion for positioning other sizes of electrodes.

2,512,706—Water-Cooled Gas-Blanketed Arc-Welding Torch—Nelson E. Anderson, Scotch Plains, N. J., assignor to Air Reduction Co., Inc., a corporation of New York.

This patent to Anderson relates to an electrode holder which has a barrel portion with a handle portion disposed at an angle to the barrel portion. Means are provided in the electrode holder for circulating water through the handle and barrel portion thereof and for supplying gas to the barrel portion of the electrode holder which positions an electrode therein.

2,513,240—Welded Steel Pipe—Erie G. Hill, Wheeling, W. Va., assignor to Wheeling Steel Corp., Wheeling, West Va., a corporation of Delaware.

Hill's pipe is a welded and threaded pipe made from basic open-hearth steel. The pipe has a specific chemical composition and is characterized by a sound weld and good field-threading properties.

2,513,323—Fluted Spot-Welding Electrode—Franz R. Hensel, Earl I. Larsen and Edman F. Holt, Indianapolis, Ind., assignors to P. R. Mallory & Co., Inc., Indianapolis, Ind., a corporation of Delaware.

This novel electrode is for use in resistance-welding operations and it comprises an elongated body having a coolant hole extending thereinto from one end thereof. This hole terminates short of a contact surface formed at an opposite end of the elongated body and a plurality of spaced longitudinally directed flutes are formed on the inner surface of the hole to increase the contact area for the coolant fluid.

2,514,060—Electric Welding Torch—Louis F. Himmelman, Teaneck, N. J.

This patented welding torch includes a hollow body having water inlet and outlet provided thereon and a tubular chuck holder positioned within the body and makes a watertight connection therewith. A chuck is secured in the chuck holder and is adapted to receive and hold an electrode therein. Water can be circulated through the hollow body and gas can be supplied to the electrode carried by the chuck to surround same.

2,514,444—Method of Resistance Welding Chian Links—Harry F. Dougherty, York, Pa., assignor to American Chain & Cable Co., Inc., Bridgeport, Conn., a corporation of New York.

In this patent, a method of welding a metallic chain link having semicircular ends and connecting sides is disclosed. The link is supported in electrodes having recesses substantially encircling the semicircular ends of the link, which recesses are formed to minimize the current flowing through the semicircular ends of the link upon creation of a potential difference between the electrodes. The electrodes are urged toward each other and a potential difference is set up therebetween to effect a welding operation on a link.

2,514,741—Cutting Torch Holder—Louis K. Bullman and Shirl Underwood, Norfolk, Va.

The patented torch holder is adapted to slide on the surface of the work and includes a protractor plate that has an arcuate slot extending along an arc of about 180° inscribed about the medial longitudinal axis of the holder in the interfacial plane between the holder and the work. A bed-plate element is adjustably carried by the arc and it has a torch tip supporting cradle provided thereon. Additional means are provided for vertical adjustment of a torch tip carried by the apparatus with relation to the work.

2,514,777—Tip for Cutting Torches—Daniel A. Marra, Cheswick, Pa.

The torch tip of this patent includes an elongate inner tubular member which has a plurality of grooves formed in its external surface. An intermediate member overlies the grooved portion of the inner member and forms with the grooves, gas passageways whereas an outer tubular member is telescopically associated with the inner and intermediate members and forms with them a gas chamber from which the gas passageways lead.

2,514,990 — Arc-Welding Mask—Leon Dewan, New York, N. Y., assignor of one-half to Percival W. Andrews, New York, N. Y.

Dewan's mask includes an outer shield having a viewing aperture therein and a rotary apertured shutter is within the shield. Driven fan means are associated with the mask for circulating air within the shield.

2,515,106—Welding Machine—John R. Wirt and Wayne H. Sheley, Anderson, Ind., assignors to General Motors Corp., Detroit, Mich., a corporation of Delaware.

In this patent an apparatus for welding an electromagnet assembly is provided, which assembly includes a coil and a core having pairs of spaced tangs at opposite ends thereof and a base having pairs of spaced tangs on opposite sides of a central region thereof. The apparatus includes means for supporting the base and the core loosely assembled together with the core tangs straddling the base tangs. Wedge and electrode means are provided for forcing the core tangs against the base tangs and means are also provided for supplying electric current to the electrodes to effect a weld between the tangs.

2,515, 176—Method of Clad Plate Resistance Welding—Frank W. Armstrong, Jr., Barberton, Ohio, assignor to The Babcock & Wilcox Co., Rockleigh, N. J., a corporation of New Jersey.

Armstrong's method includes the step of initially rolling a plurality of electrodes over a metal sheet which is superposed on and to be welded to a metal plate. A plurality of overlapping spot welds are formed in overlapped zones of the superimposed sheet and plate to secure them together. These spot welds are formed by applying a relatively low pressure to the electrodes and effecting a relatively low current flow in the electrodes and the work-

pieces and thereafter applying to the electrodes a much higher pressure during which much higher welding current flows between the electrodes and the work to complete a spot weld at a given zone.

2,515,230 — Apparatus for Electric Welding Seam Portions of Electrically Conducting Articles—Lyman L. Jones and George K. Barger, Seattle, Wash., assignors to American Can Co., New York, N. Y., a corporation of New Jersey.

This is a specific machine for welding the side-seam edges of tubular sheet-metal can bodies together and includes a pair of movable support heads for holding a pair of can bodies in opposed positions with their side-seam edges extending toward each other. Actuating means are provided for moving the support heads along separate paths to progressively advance portions of the side-seam edges of each body through a projected point of intersection of said paths of travel at which point the welding action occurs.

2,515,264—Welding Apparatus—Reidar P. C. Rasmusen, Akron, Ohio, assignor to The Babcock & Wilcox Co., Rockleigh, N. J., a corporation of New Jersey.

This patent relates to a resistance-welding machine which has a pair of electrically insulated rolling electrodes for contacting the work on the same side thereof. A separate transformer is provided for each electrode and the electrode constitutes a terminal of the secondary circuit. The transformers and individual electrodes therefor form units which are mounted for independent vertical movement. Flexible leads connect the secondaries of the units and constitute part of the secondary circuit for the pair of units and are operatively disposed between the electrodes.

2,515,300 — Heating Apparatus for Bonding Metals—Max C. Haber, Omaha, Nebr., William B. Baker, Council Bluffs, Iowa and Lloyd J. Schnavely, Cheyenne, Wyo.

A specialized type of heating apparatus including an externally threaded stationary pedestal upon the upper end of which a workpiece is adapted to rest is covered in this patent. A plurality of burners are also supported by the apparatus.

2,515,301—Gas Torch—Howard G. Hughey, Fanwood, N. J. assignor to Air Reduction Co., Inc., a corporation of New York.

A novel type of a gas torch is covered in the patent and includes a tip of the block type with means mounted on the torch for positioning one side of the tip with respect to the face of the workpiece to be operated upon. A work-engaging device is on the opposite side of the tip and a gas-distributing chamber and gas-control valve are also present in the gas torch. Movement of the work-engaging device controls flow of gas through the gas supply means dependent upon the relative positions of the work-engaging device and the block-type tip.

2,515,302—Apparatus for Controlling Relative Movement Between a Gas Torch and a Workpiece—Howard G. Hughey, Fanwood, N. J., assignor to Air Reduction Co., Inc., a corporation of New York.

This apparatus is for thermochemically removing metal from a ferrous metal workpiece and includes a gas torch and means including an electric motor for producing relative movement between the torch and the workpiece. Other means supply cutting oxygen to the gas torch and control means including a circuit breaker are provided in the circuit of the motor to render same inoperative when the oxygen pressure falls to a predetermined value.

2,515,559—Arc Welding in Inert Atmospheres—John Frederick Lancaster and William King Bates, Marshall, London, England, assignors to A. P. V. Co., Ltd., London, England

This patent is on a tungsten electrode which has therein 0.1 to 3% of finely divided thoria.

2,515,634, 5, 6—Condenser Welding System—John W. Dawson, West Newton, Hans Klemperer, Belmont, Mass. assigners to Raytheon Mfg. Co., Newton, Mass., a corporation of Delaware.

These patents cover a specialized electrical and condenser charging system and patent No. 2,515,636 is particularly directed to a welding system wherein at least one movable electrode is provided with control means for moving same, and a condenser is provided with a circuit for discharging into the weld load. Means responsive to the voltage on the condenser are provided to prevent operation of the electrode moving means when the condenser is charged below a predetermined level.

2,516,016—Arc Welding Apparatus—William E. Pakala, Pittsburgh, Pa., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

Pakala's patent covers the combination with an arc-welding system of an auxiliary electrode which is disposed in an arcing relation with a main electrode. A high-frequency generator is connected to apply its voltage between the auxiliary and the welding electrodes.

2,516,037—Arc-Welding Apparatus—Clifton S. Williams, Pittsburgh, Pa., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

This arc-welding apparatus includes a main electrode connected to a single-phase source of welding current and an auxiliary electrode disposed in insulated relation to the main electrode and connected to the same source of welding current through an impedance device. The auxiliary arc is maintained between the main and auxiliary electrodes only until an arc is established between the main electrode and workpiece.

LIST OF NEW MEMBERS

July 1, to July 31, 1950

BIRMINGHAM
Seale, Buford B. (C)

BOSTON
Richardson, George (C)
Russell, James G., Jr. (B)

BRIDGEPORT
Oertel, John W. (B)

CHICAGO
McCauley, Roy Barnard, Jr. (B)
Zeller, Matthew (C)

CLEVELAND
Briggs, Charles W. (B)
Sawyer, Ansley W., Jr. (C)

DALLAS
Wood, Robert G. (C)

DETROIT
Evans, William J. (B)
Renfree, Edward W. (C)

HARTFORD
Brautigam, Hugh M. (C)

HOUSTON
Kuhn, C. D. (B)

MILWAUKEE
Stern, Peter (B)

NEW JERSEY
Boam, Willard M. (B)

NEW YORK
Ryan, J. F. (B)
Waechter, Theodore F. (B)

NORTHWEST
Halvorson, Harry E. (D)

PEORIA
Sloter, Oakley Howard (C)

PHILADELPHIA
Eckler, Charles A. (C)
Nicholls, Thomas R. (C)

RICHMOND
Harvey, Robert H. (C)
Mobley, A. J. (B)

ST. LOUIS
Harrelson, Dewitt T. (B)

SYRACUSE
Folts, George S. (C)

WESTERN MICHIGAN
Bell, Preston C. (B)

NOT IN SECTIONS
Graser, R. F. (C)
Kaminer, James H. (B)

TENTATIVE PROGRAM

AMERICAN WELDING SOCIETY

31st Annual Meeting
week of October 22, 1950

HOTEL SHERMAN, CHICAGO, ILL.

Welding and cutting demonstration will be featured at the National Metal Exposition held during the week in the Chicago International Amphitheatre

TECHNICAL SESSIONS

All Technical Sessions will positively start on time.

No Stenotype Reporter—Members desiring to discuss papers are urgently requested to prepare discussion in writing in advance of the meeting and to send copies to Headquarters, as those preparing written discussion will be given preference at the session. Members and guests giving extemporaneous discussion at meeting should forward a written discussion as soon as possible after the meeting.

SUNDAY AFTERNOON, OCTOBER 22nd—5:00 P.M.

President's Reception

Ball Room

MONDAY MORNING, OCTOBER 23rd—9:30 A.M.

Three Simultaneous Sessions

WELDABILITY

Ball Room

Chairman—R. E. SOMERS
Bethlehem Steel Co.

Co-Chairman—L. C. BIBBER
Carnegie Illinois Steel Corp.

The Influence of Low-Temperature Cooling Rates Following Welding on the Ductility of Arc Welds in Mild Steel
by A. E. FLANIGAN, S. I. BOCARSKY and G. B. McGUIRE, University of California

The Effect of Nitrogen on Brittle Behavior of Mild Steel
by G. H. ENZIAN and G. J. SALVAGGIO, Jones & Laughlin Steel Corp.

The Micro-Mechanism of Fracture of Structural Steels in the Tension Impact Test
by W. H. BRUCKNER, University of Illinois

Influence of Biaxiality on Notch Brittleness
by D. ROSENTHAL, University of California, and W. D. MITCHELL, Douglas Aircraft

RESISTANCE WELDING

Louis XVI Room

Chairman—JACK OGDEN
Fisher Body Div., General Motors Corp.

Co-Chairman—R. E. POWELL
Western Electric Co.

Development of Production Welding Techniques
by J. RAYMOND WIRT, Delco-Remy Division, General Motors Corp.

Spot Welding of Thin Materials with Short Time-Constant Equipment
by FRANKLIN PAGE, JR., Du Fresne and Page Engineering Co., and FRANK JOHNSON, Unitek Corp.

Problems in the Design and Operation of Tube Mills for High-Speed Production
by DONALD H. FLEIG, American Electric Fusion Corp.

The Spreading Resistance of Contacts
by DR. W. B. KOUWENHOVEN, The Johns Hopkins University, and W. T. SACKETT, JR., Battelle Memorial Institute

SURFACING

Crystal Room

Chairman—T. B. JEFFERSON
The Welding Engineer

Co-Chairman—R. L. TOWNSEND
Tweco Products Co.

Some Characteristics of Composite Tungsten Carbide Weld Deposits
by H. S. AVERY, American Brake Shoe Company

Hard Facing of Steam Valve Seats and Disks
by O. E. SWENSON, U. S. Naval Engineering Experiment Station

New Production Applications of Hard Facing
by ELDON C. HURT, Haynes Stellite Division, Union Carbide and Carbon Corp.

The Present Status of Composite Metal Fabrication by Arc Welding
by H. E. CABLE, The Lincoln Electric Company

MONDAY AFTERNOON, OCTOBER 23rd—2:00 P.M.

Three Simultaneous Sessions

FLAME HARDENING

Crystal Room

Chairman—A. F. CHOUINARD
National Cylinder Gas Co.

Co-Chairman—E. C. BREKELBAUM
Harnischfeger Corp.

Commercial Flame Hardening
by E. J. COX, Pittsburgh Commercial Heat Treating Co.

Flame Hardening of Large Surfaces
by J. J. BARRY, Air Reduction Sales Co.

Production Flame Hardening
by MILTON GARVIN, Cincinnati Milling Machine Co.

ARCS, ELECTRODES & FLUXES

Louis XVI Room

Chairman—C. I. MAC GUFFIE
General Electric Co.

Co-Chairman—H. E. ROCKEFELLER
The Linde Air Products Co.

Research Techniques for Study of Arcs in Inert Atmospheres
by ROGER H. GILLETTE, The Linde Air Products Co., and R. T. BREYMEIER, Union Carbide and Carbon Research Labs., Inc.

Aluminum-Magnesium Filler Metals for Welding High-Strength Aluminum Alloys
by R. D. WILLIAMS and D. C. MARTIN, Battelle Memorial Institute

Characteristics of Inert-Gas-Shielded Metal Arcs
by ALBERT MULLER, G. R. ROTHSCHILD, and W. J. GREENE, Air Reduction Co., Inc.

RESEARCH

Ball Room

Chairman—PERRY R. CASSIDY
Babcock & Wilcox Co.

Co-Chairman—F. L. PLUMMER
Hammond Iron Works

Room Temperature Tensile Tests as an Index of Transition Temperature of Steel Plates
by S. S. TÖR, R. D. STOUT and BRUCE G. JOHNSTON, Lehigh University

Interpretative Report, Fabrication Division, PVRC
by H. C. BOARDMAN, Chicago Bridge & Iron Co.

Plastic Deformation of Weldments Under Combined Stresses
by WILLIAM S. PELLINI, and C. E. HARTBOWER, Naval Research Laboratory

---

PANEL DISCUSSION ON RECOMMENDED PRACTICES FOR RESISTANCE WELDING—2:00 P.M.

SPONSORED BY A.W.S. RESISTANCE WELDING COMMITTEE

Bal Tabarin Room

Chairman—J. HEUSCHKEL, Westinghouse Electric Corp.
Co-Chairman—J. J. MAC KINNEY, The Budd Co.

Historical Background
by WILSON SCOTT, Westinghouse Electric Corp.

Keynote of Quality
by R. T. GILLETTE, General Electric Co.

Aluminum and Magnesium Alloys
by W. J. WILSON, Lavelle Aircraft Corp.

Copper Alloys and Dissimilar Nonferrous Metals
by J. B. WELCH, Cutler-Hammer, Inc.

Carbon and Low-Alloy Steels
by J. HEUSCHKEL, Westinghouse Electric Corp.

Nickel and Nickel Alloys
by R. M. WILSON, Jr., The International Nickel Co.

Stainless Steels
by J. J. MAC KINNEY, The Budd Co.

Coated Materials
by E. A. BUSSARD, Coleman Co., Inc.

High-Speed Motion Pictures

Summary and Adjournment

MONDAY AFTERNOON—4:30 P.M.

EDUCATIONAL LECTURE SERIES—Chairman—DR. GILBERT E. DOAN

Louis XVI Room

Presiding—FRED L. PLUMMER
Hammond Iron Works

Aluminum: Properties, Design, Procedure, Inspection and Application
by G. O. HOGLUND, Engineer, Aluminum Company of America

MONDAY EVENING, OCTOBER 23rd—8:00 P.M.

Ball Room

AWARD OF PRIZES AND MEDALS

Chairman—O. B. J. FRASER
President, American Welding Society

Co-Chairman—H. R. MORRISON
Chairman, Convention Committee

1950 ADAMS LECTURE

Dynamic Characteristics of DC Welding Machines
by C. H. JENNINGS, Westinghouse Electric Corporation

TUESDAY MORNING, OCTOBER 24th—9:30 A.M.

Three Simultaneous Sessions

PIPE FABRICATION

Crystal Room

Chairman—D. H. COREY
The Detroit Edison Co.
Co-Chairman—E. R. SEABLOOM
Crane Company

Development of Welding Procedure for High Pressure, High Temperature Steam Piping
by N. L. NAVARRE, U. S. Naval Engineering Experiment Station

Fabrication and Welding of High Pressure-High Temperature Alloy Piping
by H. J. IRRGANG, Jr., W. K. Mitchell & Co.

Design and Installation of Large Diameter, Long Span, Welded Pipe
by HORACE JACKSON, Thompson Pipe and Steel Co.

Welding of Heavy Wall Type 347 Stainless Steel Piping
by R. W. EMERSON, Pittsburgh Piping & Equipment Co.

RESISTANCE WELDING

Louis XVI Room

Chairman—T. EMBURY JONES
Precision Welder & Machine Co.
Co-Chairman—R. C. MC MASTER
Battelle Memorial Institute

A Practical Method for Obtaining Consistent Resistance Welds
by J. W. KEHOE, Westinghouse Electric Corp.

Variables in Cross-Wire Welding Dissimilar Metals
by I. S. GOODMAN, Westinghouse Electric Corp.

Resistance Spot and Seam Welding of Aircraft Materials Using DC Current
by J. H. COOPER, The Taylor-Winfield Corp.

The Projection Welding of 0.010- and 0.020-In. Steel Sheet
by E. F. NIPPES, J. M. GERKEN and J. G. MACIORA, Rensselaer Polytechnic Institute

SHIP STRUCTURE

Ball Room

Chairman—CAPT. C. M. TOOKE
Bureau of Ships
Co-Chairman—COMDR. R. D. SCHMIDTMAN, U. S. Coast Guard

Work of the Ship Structure Committee
by REAR ADMIRAL K. K. COWART, U. S. Coast Guard

Welded Reinforcement of Openings in Structural Steel Members
by D. VASARHELYI, and R. A. HECHTMAN, University of Washington

The Determination of Initial Stresses and Results of Tests on Steel Plates
by PROF. E. W. SUPPIGER, DR. CARLO RIPARBELLI and E. R. WARD, Princeton University

Some Metallurgical Aspects of Ship Steel Quality
by H. M. BANTA, R. H. FRAZIER and DR. C. H. LORIG, Battelle Memorial Institute

---

TUESDAY AFTERNOON, OCTOBER 24th—2:00 P.M.

Three Simultaneous Sessions

RESISTANCE WELDING

Crystal Room

Chairman—B. L. WISE
National Electric Welding Mach. Co.

Co-Chairman—J. F. RANDALL
Ford Motor Co.

Optimum Flash Welding Conditions for Aluminum Alloys—The Importance of Upset Variables
by E. F. NIPPES, W. F. SAVAGE, P. PATRIARCA and J. J. McCARTHY, Rensselaer Polytechnic Institute

Flash Welding Nonferrous Materials
by F. L. BRANDT, JR., Thomson Electric Welder Co.

Spot Welding of Scaly Heavy-Gage Structural Steel
by E. F. NIPPES, RAMSEY and J. G. MACIORA, Rensselaer Polytechnic Institute

DESIGN

Special Luncheon—12:30—Bal Tabarin Room

Introduction—H. R. MORRISON
Design for Production Economies
by G. F. NORDENHOLT, Editor, *Product Engineering*
Technical Session: Design for Production Economies

Louis XVI Room

Chairman—G. F. NORDENHOLT
Product Engineering

Co-Chairman—H. W. PIERCE
New York Shipbuilding Corp.

Organization for Design for Production Economy
by T. J. CRAWFORD, Consulting Engineer
Economies Accomplished by Redesign for Welding
by KENNETH JACKSON, Caterpillar Tractor Co.
Applications of Welded Design for Cost Reduction
by R. H. BENNEWITZ, The Linde Air Products Co.

SHIP STRUCTURE

Ball Room

Chairman—D. P. BROWN
American Bureau of Shipping

Co-Chairman—FINN JONASSEN
National Research Council

Notch Sensitivity of Welded Ship Plate by Explosion Test
by G. S. MIKHALAPOV, Metallurgical Research and Development Co., Inc.

Stress Studies of Welded Ship Structure Specimens
by WM. R. CAMPBELL, Engineering Mechanics Section, National Bureau of Standards

The Distribution of the Locked-In Stresses in a Large Welded Steel Box Girder
by JOHN VASTA, Bureau of Ships, Navy Department

TUESDAY AFTERNOON—4:30 P.M.

EDUCATIONAL LECTURE SERIES—Chairman—DR. GILBERT E. DOAN

Bal Tabarin Room

Presiding—D. H. COREY
Detroit Edison Company

Copper: Properties, Design, Procedure, Inspection and Application
by J. R. HUNTER, Manager, Welding Section, Research Department, Revere Copper and Brass Co., Inc.

TUESDAY EVENING, OCTOBER 24th—8:00 P.M.

Applied Welding Engineering

A Symposium on Proper Application of Welding Processes

SPONSORED BY A.W.S. TECHNICAL ACTIVITIES COMMITTEE

Bal Tabarin Room

Chairman—C. D. EVANS, Chairman, Technical Activities Committee
Co-Chairman—S. A. GREENBERG, Technical Secretary, A. W. S.

Introduction
by C. D. EVANS, International Harvester Co. (*Chairman*, Technical Activities Committee)

Design
by J. J. CHYLE, A. O. Smith Corp. (*Chairman*, Automotive Welding Committee)

Materials
by A. N. KUGLER, Air Reduction Sales Co. (*Chairman*, A.W.S. Committee on Brazing and Soldering)

Workmanship
by R. W. CLARK, General Electric Co. (*Chairman*, A.W.S. Committee on Standard Qualification Procedures and A.W.S. Army Ordnance Advisory Committee)

Inspection
by J. LYELL WILSON, Consulting Engineer (*Vice-Chairman*, Technical Activities Committee and *Chairman*, A.W.S. Committee on Welding in Marine Construction)

Applications
by S. A. GREENBERG, Technical Secretary, American Welding Society

Discussion

WEDNESDAY MORNING, OCTOBER 25th—9:30 A.M.

Three Simultaneous Sessions

RESEARCH

Louis XVI Room

Chairman—G. E. CLAUSSEN
Reid-Avery Company

Co-Chairman—O. T. BARNETT
Metal & Thermit Corp.

The Rotary Electrode for Manual Metallic Arc Welding
by PROF. GILBERT S. SCHALLER, University of Washington

Effects of Reduced Atmospheric Pressures on Arc Welding Characteristics
by M. L. BEGEMAN, B. H. AMSTEAD and U. I. MASHRUWALA, Dept. of Mechanical Engineering, The University of Texas

Transformation of Austenite in a Manganese-Molybdenum Steel Deposited as Weld Metal
by O. O. MILLER, F. C. KRISTUFEK and R. H. ABORN, United States Steel Corp.

Stress Relieving and Fracture Strength
by D. SWAN, A. R. LYTLE and C. MC KINSEY, Union Carbide & Carbon Res. Labs., Inc.

EDUCATION

Bali Room

Chairman—R. S. GREEN
Ohio State University

Co-Chairman—M. L. BEGEMAN
The University of Texas

SYMPOSIUM ON THE NEED OF PROFESSIONAL TRAINING FOR THE WELDING ENGINEER

Employer Point of View:

Viewpoint of Representative of Bureau of Ships, Navy Dept.
by A. G. BISSELL, Bureau of Ships, Navy Department

Viewpoint of Representative of Industrial Research
by J. HEUSCHKEL, Westinghouse Electric Corporation

Viewpoint of Representative of Fabrication Industry
by J. J. CHYLE, A. O. Smith Corporation

What Is Needed in the Professional Training of a Welding Engineer
by DR. J. M. PARKS, Welding Research, Armour Research Foundation

Viewpoint of Representative of an Eastern Private University
by DR. G. E. DOAN, Prof. of Metallurgy, Lehigh University

Viewpoint of Representative of a Private Engineering School
by PROF. R. A. WYANT, Asst. Prof., Department of Metallurgy, Rensselaer Polytechnic Institute

College Point of View:

Viewpoint of Representative of a Western State University
by PROF. G. S. SCHALLER, Prof. Mechanical Engineering, University of Washington

Presentation of papers to be followed by an Authors' Round Table Discussion and General Discussion.

STRUCTURAL

Crystal Room

Chairman—L. S. MC PHEE
Whiting Corporation

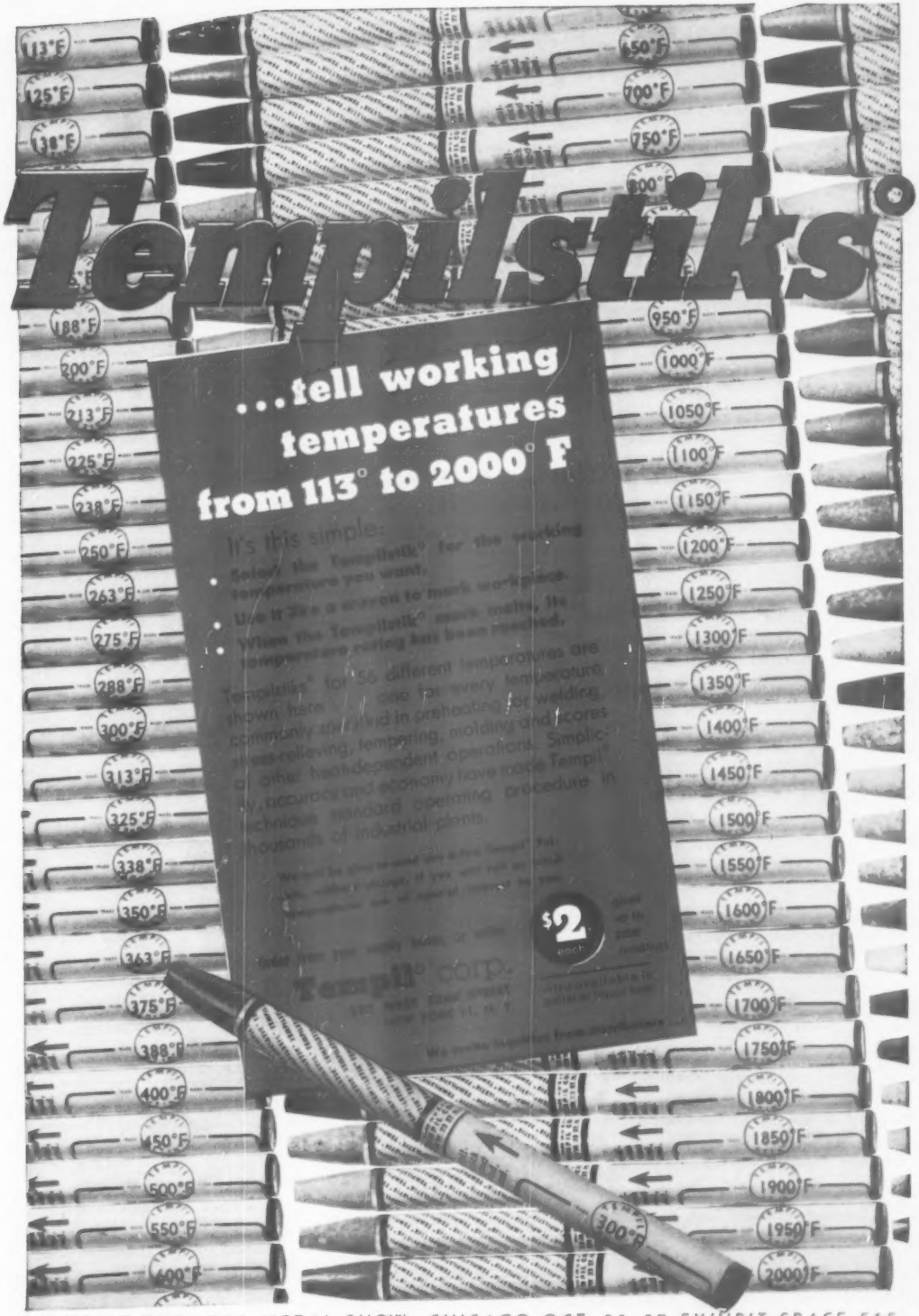
Co-Chairman—J. E. BOBERG,
Chicago Bridge & Iron Co.

Connections for Welded Rigid Portal Frames
by A. ANTHONY TOPRACTSOGLOU, LYNN S. BEEDLE, and BRUCE G. JOHNSTON, Lehigh University

Stress Redistribution Above the Elastic Limit for a Welded Frame
by L. E. GRINTER, and JOHN BUTKUS, Illinois Institute of Technology, and CHARLES G. PELLER, Valparaiso University

Buckling of Intermittently Supported Rectangular Plates
by C. H. NORRIS, D. A. POLYCHRONE and L. J. CAPOZZOLI, Massachusetts Institute of Technology

Welded Eccentric Girders for Composite Bridge Construction
by R. E. ROBERTSON, Consulting Engineer, Saxe, Williar and Robertson



SEE US AT THE 1950 METAL SHOW—CHICAGO OCT. 23-27 EXHIBIT SPACE 515

WEDNESDAY AFTERNOON, OCTOBER, 25th—2:00 P.M.

Three Simultaneous Sessions

MACHINERY AND MAINTENANCE

Louis XVI Room

Chairman—R. E. MC FARLAND
Western Electric Co.

Co-Chairman—J. C. MENZIES
J. C. Menzies & Co.

Welding as Used in the Manufacture of Farm Tractors
by J. L. BUCHHOLZ, International Harvester Co., Farmall Works.

Tubular Sections in Frame Design of Hydraulic Benders
by E. J. DeWITT, Wallace Supplies Mfg. Co.

Electric Utility Welding in the Shop and Field
by DAVID P. O'CONNOR, Department of Water and Power, City of Los Angeles, Calif.

CONTROLS, STANDARDS

Ball Room

Chairman—J. LYELL WILSON
Consulting Naval Architect

Co-Chairman—ROGER CLARK
General Electric Co.

Procedure Approval Tests
by S. S. KATSEF, U. S. Naval Engineering Experiment Station

Better Welding at Lower Costs
by LEW GILBERT, Editor, *Industry and Welding*

Suggested New Welding Standards
by J. F. LINCOLN, The Lincoln Electric Company

MACHINE WELDING

Crystal Room

Chairman—F. E. MC ATEE
Chicago Bridge & Iron Co.

Co-Chairman—AMEL R. MEYER
Graver Tank & Mfg. Co.

Welding with Multiple Electrodes in Series in Submerged Melt Welding
by E. L. FROST, and A. R. LYTLE, Union Carbide and Carbon Research Labs., Inc.

Automatic Welding in Steel Mill Maintenance
by W. P. HOFFMAN, International Harvester Company, Wisconsin Steel Works

---

WEDNESDAY AFTERNOON—4:30 P.M.

EDUCATIONAL LECTURE SERIES—Chairman—DR. GILBERT E. DOAN

Louis XVI Room

Presiding—J. J. CHYLE
A. O. Smith Corporation

Nickel: Properties, Design, Procedure, Inspection and Application
by R. M. WILSON, JR., Welding Engineer, International Nickel Co., Inc.

WEDNESDAY EVENING, OCTOBER 25th

SECTION & NATIONAL OFFICERS DINNER—6:30 P.M.
Louis XVI Room

BUSINESS MEETING AND SECTION OFFICERS CONFERENCE—7:30 P.M.
Louis XVI Room

UNIVERSITY RESEARCH DINNER—6:30 P.M.
Jade Room

UNIVERSITY RESEARCH CONFERENCE—7:30 P.M.
Crystal Room

THURSDAY MORNING, OCTOBER 26th—9:30 A.M.

Three Simultaneous Sessions

NONFERROUS METALS

Louis XVI Room

Chairman—C. H. JENNINGS
Westinghouse Electric Corp.

Co-Chairman—A. M. SETAPEN
Handy & Harman

Welding Aluminum with Inert Arc D. C.
by JOHN W. MORTIMER, Whitlock Mfg. Co.

The Effect of Welding on the Properties of Titanium-Carbon Alloys
by E. M. MAHLA and R. B. HITCHCOCK, E. I. duPont de Nemours & Co.

Aircomatic Welding of Copper-Base Alloys
by HAROLD ROBINSON and J. H. BERRYMAN, Air Reduction Co., Inc.

Copper Alloy Brazing for Production Economy
by CLINTON E. SWIFT and E. B. BROWN, The American Brass Co.

PRESSURE VESSELS

Ball Room

Chairman—W. B. BUNN
M. W. Kellogg Company

Co-Chairman—K. L. WALKER
Foster Wheeler Corp.

Stress Concentration Problems in Welded Construction at Atmospheric and Elevated Temperatures
by G. J. GREEN and D. H. MARLIN, Dravo Corp.

Multiple Layer Submerged Arc Welding of Pressure Vessels
by L. C. STILES and D. H. CURRY, Chicago Bridge & Iron Co.

General Procedure for Fabrication of Pressure Vessels
by S. V. WILLIAMS, A. O. Smith Corp.

Welding of Stainless Steel Containers to Meet Sanitary Standards
by P. H. MOUNTS, Cherry-Burrell Corp.

AIRCRAFT

Crystal Room

Chairman—J. B. JOHNSON
Office of Research, U.S.A.F.

Co-Chairman—S. L. HOYT
Battelle Memorial Institute

Heliarc Welding in Production
by T. E. PIPER, Northrup Aircraft, Inc.

The Evaluation of Factors Influencing the Crack Sensitivity of Several Aircraft Steels
by A. W. STEINBERGER, B. J. DeSIMONE and J. STOOP, Curtiss-Wright Corp.

Some Basic Problems in Design for Aircraft Welding
by J. KOZIARSKI and K. B. GILLMORE, Piasecki Helicopter Corp.

Jigs and Fixtures for Inert Gas Arc Welding
by H. A. HUFF, JR., and A. N. KUGLER, Air Reduction Sales Co.

THURSDAY AFTERNOON, OCTOBER 26th

Inspection Trip—1:00 P.M.

ELECTRO-MOTIVE DIVISION OF G.M.C.—PLANT #2

BOARD OF DIRECTORS
LUNCHEON AND MEETING—12:30
Jade Room

FRIDAY MORNING, OCTOBER 27th—9:30 A.M.

Three Simultaneous Sessions

INERT-GAS METAL-ARC WELDING

Ball Room

Chairman—G. O. HOGLUND
Aluminum Co. of America

Co-Chairman—S. M. SPICE
Buick Div., General Motors Corp.

Alrcomatic Welding of Nickel and Stainless Clad Steels
by T. T. WATSON and R. R. ROTHERMEL, Lukens Steel Co.

Alrcomatic Welding of Austenitic Nickel-Chromium Stainless Steel
by W. G. BENZ, JR., and J. S. SOHN, Air Reduction Co., Inc.

Argon Metal Arc Welding Nonferrous Metals and High- and Low-Alloy Steels
by H. T. HERBST, The Linde Air Products Co.

Construction of Welded Aluminum Ammonium Nitrate Prilling Tower
by H. N. HOCKENSMITH, Brown & Root, Inc.

OXYGEN CUTTING

Crystal Room

Chairman—E. V. DAVID
Air Reduction Sales Co.

Co-Chairman—R. S. BABCOCK
The Linde Air Products Co.

The Use of Electronically Guided Template Tracing Devices in Shape Flame Cutting
by R. O. FISH, Fairbanks, Morse & Co.

Foundry Applications for Oxygen, Acetylene and Other Gases
by G. E. BELLEW, Air Reduction Sales Co.

Production Edge-Preparation and Shaping of Plate for Welding
by C. A. HEFFERNON, The Linde Air Products Co.

Design Around a Process
by R. F. HELMKAMP, Air Reduction Sales Co.

LOCOMOTIVES AND RAILROADS

Louis XVI Room

Chairman—H. E. GANNETT
Consulting Railroad Engineer

Co-Chairman—JOHN H. HRUSKA
Consulting Engineer

Fabrication of Main Line and Switcher Locomotives
by FRED T. PERRY, General Electric Co.

Reclamation of Diesel Locomotive Parts
by LaMOTTE GROVER and R. L. REX, Air Reduction Co., Inc.

Economy of Reclamation by Welding at the Railroad Reclamation Plant
by W. G. MUSCHLER, Chicago, Burlington & Quincy Railroad

Rehabilitation of Ore Cars
by J. F. LIKARISH, Great Northern Railway Co.

WELDING METALLURGY

The internationally known book on the above subject originally written by Henry & Claussen has been completely revised, enlarged and brought up to date by G. E. Linnert. A book of 505 pages, handsomely bound, price $2.50. Order your copy now! American Welding Society.

DO YOU DISPLAY YOUR A.W.S. CERTIFICATE?

Our Certificate certifies your Membership and signifies that you are contributing to advancing the Science and Art of Welding by active participation in the American Welding Society.

For those who have not received their A.W.S. Membership Certificate, we can supply such on order with your name engrossed thereon and signed by the Society's President and Secretary. Order through National Headquarters, 33 West 39th St., N. Y. C. Price $1.00. (Money Order or check)

COBALT 60

This fast, highly practicable and economical source of gamma radiation is now freely available. Orders for any amount can be filled promptly for

INDUSTRIAL RADIOGRAPHY of HEAVY METAL CASTINGS, WELDMENTS, PIPES-ETC.

Less costly than radium, Eldorado High Specific Activity Cobalt 60 is ideal for use where short exposure time and small focal spot are desirable.

For further information and manual on Cobalt 60 and radium in industrial radiography, write to Dept. Z,

ELDORADO RADIUM

ELDORADO MINING & REFINING (1944) LTD.

P. O. BOX 379 *OTTAWA, CANADA*

WELDING CODES STANDARDS and SPECIFICATIONS

Are you fully informed on the latest welding standards available? Have you missed any of the earlier standards? This column is published as a regularly monthly feature of The Welding Journal to keep you abreast of A.W.S. technical standards, which are universally recognized as the most authoritative source of welding information.

The list of publications shown below is only partial; it is changed from month to month.

Keep informed—Read this column regularly

A. FUNDAMENTALS OF WELDING

Definitions, Symbols, Testing, Filler Metal

A2.0-47 Standard Welding Symbols	$1.00
A2.1-47 Symbols Wall Chart	50c
A3.0-49 Standard Welding Terms and Their Definitions	$1.00
A3.1-49 Master Chart of Welding Processes and Process Charts	50c
A3.0-49 and A3.1-49 together	$1.50
A4.0-42 Standard Methods for Mechanical Testing of Welds (with 1945 Supplement)	50c
*A5.1-48T Specifications for Mild Steel Arc-Welding Electrodes (Tentative)	35c
*A5.2-46T Specifications for Iron and Steel Gas-Welding Rods (Tentative)	25c
*A5.4-48T Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Welding Electrodes (Tentative)	25c
*A5.5-48T Specifications for Low-Alloy Steel Arc Welding Electrodes (Tentative)	35c
*A5.6-48T Specifications for Copper and Copper-Alloy Metal Arc Welding Electrodes (Tentative)	25c
A6.0-40 Recommended Procedure to be Followed in Preparing for Welding or Cutting Certain Types of Containers Which Have Held Combustibles	50c

NOTE: 25% discount to A and B members and 15% discount to C members of AWS on copies of any codes and standards listed above except starred items.

Send your orders, or requests for Order Forms containing complete list of AWS publications to:

Dept. T,
American Welding Society
33 West 39th Street
New York 18, N. Y.

WELDING RESEARCH COUNCIL

of the Engineering Foundation

Sponsored by the American Welding Society and American Institute of Electrical Engineers American Institute of Mining and Metallurgical Engineers, American Society of Civil Engineers American Society of Mechanical Engineers, and Society of Naval Architects and Marine Engineers

Supplement to The Welding Journal, September, 1950

The Influence of Biaxiality on Notch Brittleness

In determining ductility transition temperature restraint to plastic flow is determined not only by stress concentration but also by the state of stress in the notched section

by D. Rosenthal and W. D. Mitchell

Abstract

The embrittling effect of a notch, or the so-called notch sensitivity, in mild-steel flat specimens subjected to tension and bending has been investigated by means of the ductility transition temperature, i.e., the temperature or range of temperatures below which the specimens exhibited a marked loss of ductility. The following variables were studied: (*a*) thickness of the specimens, (*b*) depth and (*c*) the radius of the notch. However, the last two quantities were varied in such a way as to keep constant the value of the stress-concentration factor at the bottom of the notch. This factor is defined as the ratio of the actual stress at the bottom of the notch to the stress which would have existed at this point in the absence of the notch. It was found that, as the specimens became thinner, the transition temperature approached the same value regardless of the depth and radius of notch. On the other hand, as the specimens were made thicker, the deeper notches gave higher transition temperatures than the more shallow ones despite the same value of the stress-concentration factor. On the basis of the above results it was concluded that the combined increase of thickness of specimen and depth of notch created a triaxial stress field below the surface of the notch and that the degree of triaxiality of this field was the major factor responsible for the notch sensitivity. Further tests are necessary to clarify the significance of the stress-concentration factor.

D. Rosenthal is Professor of Engineering, University of California, Los Angeles, Calif. and W. D. Mitchell is with Douglas Aircraft Co., Santa Monica, Calif.

Investigation sponsored by the Welding Research Council of the Engineering Foundation. Part of this material was used for a thesis by W. D. Mitchell in partial satisfaction for the requirements for the degree of Master of Science in Engineering.

Scheduled for presentation at Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

INTRODUCTION

THE failure of welded structures in recent years has directed much attention to the study of notch embrittlement and its causes. The reason for this trend lies in the fact that almost every welded joint by virtue of its geometry acts as a notch in so far as the mechanical behavior of the structure is concerned. Tests performed on full-scale welded sections[15, *] have been instrumental in demonstrating the role of the geometry in the phenomenon of embrittlement of mild-steel weldments. But they have been less appropriate to a detailed analysis of the embrittling factors of a purely geometrical nature owing to the presence of other factors, e.g., of a physico-chemical nature, which accompany the welding operation. In order to obtain a clear understanding of the geometrical factors of embrittlement the recourse to a specimen in which the notch is the only variable involved appears necessary.

One factor which in the past investigations of the notched specimen has received more attention than any other is the stress raiser, or stress concentration as produced by the notch. This factor is defined as the ratio of the stress at the bottom of the notch to the stress which would have existed at this point without the notch for the same applied load. For the purpose of computation a purely elastic behavior is assumed; yet there is sufficient evidence which has also been corroborated by the present work,** that even in the case of the most brittle type of fracture a nonnegligible amount of plastic deformation exists at and near the notch.

* Superiors refer to bibliography at the end of the paper.

** See Appendix 3.

This finding casts considerable doubt on the validity of the above computation.

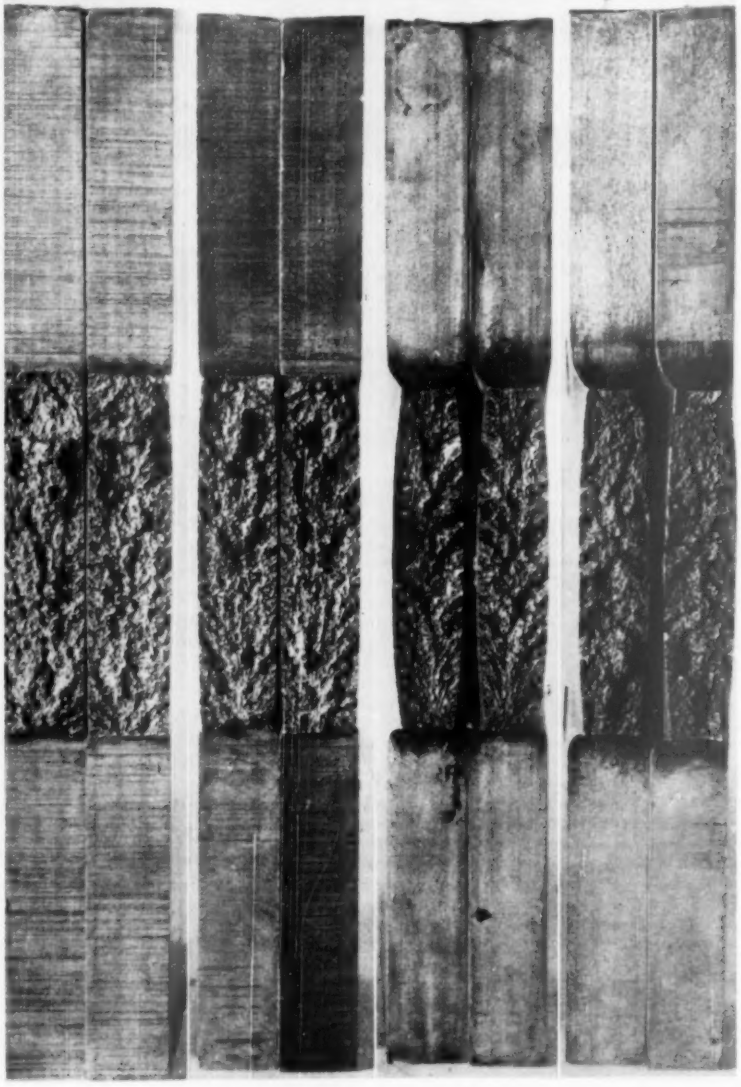
A second factor of embrittlement, as pointed out by Holloman,[1] is the increase of strain rate resulting from a higher strain, or strain concentration, at the base of the notch. Unlike the stress concentration, the strain-concentration concept appears to be valid in the plastic range.[12] However, previous investigations[4] have indicated that an increase of strain rate by as much as a multiple of five is insufficient to account for the great difference in the embrittlement of notched and unnotched coupons. Thus the presence of a notch must produce other effects beside the increase in strain rate.

A third embrittlement factor was demonstrated by Maurer and Mailander.[5] It is the increase of the thickness of flat-notched coupons. This factor has been discussed by Zener and Holloman[1] who have attributed the phenomenon to the presence of a biaxial state of stress at the notch. It is known that in a two dimensional stress field the onset of plastic flow can occur at a higher value of the maximum normal stress. On this basis the increase of embrittlement could be attributed to the fact that the maximum normal stress has approached closer to some critical value of fracture.

In addition to the above factors, a biaxial state of stress exists on the face of a flat-notched coupon, which is a function of the depth and sharpness of the notch. Recently,[10] the question was raised as to how much the above state of stress would influence the embrittlement of a notched coupon. In view of the lack of a clear indication in the literature an attempt has been made in the investigation reported herein to obtain more conclusive evidence on the influence of this factor.

THE EMBRITTLEMENT OF STEEL: THE DUCTILITY TRANSITION TEMPERATURE

It is known[1] that a steel structure at normal temperatures will absorb a large amount of energy before failure occurs, but as the temperature is lowered the amount of energy decreases in a rather unpredictable fashion, depending upon the characteristics of the steel, the method of fabrication (welded or not welded) and the type of loading. Simultaneously with the drop of energy, a change in the mode of fracture is observed. As the temperature is lowered a change from a fibrous (shear mode) to a granular (cleavage mode) fracture occurs over a certain temperature range. A drop of absorbed energy also occurs over this range, but as pointed



I II III IV

Fig. 1. The ductility transition, specimens I and II, and the fracture transition, specimens III and IV, in notched tensile specimens

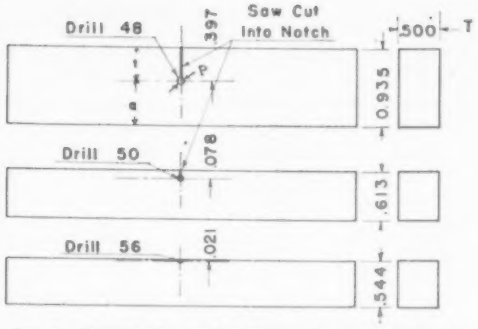


Fig. 2. Details of modified Charpy-impact specimens

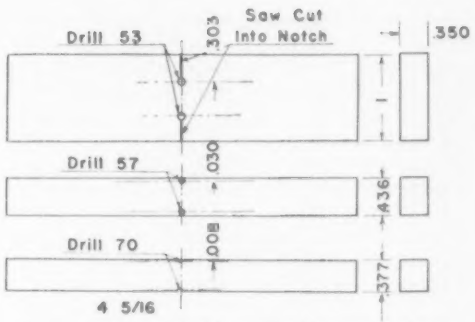


Fig. 3. Details of double-notched impact specimens

out by Vanderbeck and Gensamer,[3] in many types of test specimens the total energy absorbed in a granular type of fracture is still a high percentage of that absorbed in the fibrous fracture, cf. Fig. 1. As the temperature is lowered still further, the absorbed energy continues to decrease. For some specimens and some steels a point is reached at which the energy absorbed drops suddenly to an extremely low value and remains at very nearly this value for all lower temperatures. The latter drop in energy has been called[3] the transition to a brittle fracture, or for simplicity the ductility transition, while the former has been designated as the fracture transition. Thus with some specimens there are two distinct transitions, for others the two may coincide or so very nearly coincide as to appear as one.

Because of this particular influence of temperature on the amount of deformation of steel before fracture, the transition temperature appears as a convenient indicator of the embrittlement. Thus a shift of the transition temperature toward higher values would indicate that the factors involved favor embrittlement, and vice versa. As will appear later, all our specimens exhibited a more or less sudden decrease of energy absorption in a certain range of temperature. Therefore, we have adopted the ductility rather than the fracture transition temperature as an indication of brittleness.

SELECTION OF SPECIMENS

For the purpose of comparison all specimens were designed upon the Neuber theory[7] with the same stress-concentration factor equal to three. This factor may be represented as a function of two ratios: a/p and t/p, where a is the depth of the material behind the notch, t is the depth of the notch and p is the radius of the notch, Fig. 2. The degree of biaxiality on the face of the specimen was varied by modifying the depth of the notch, while the degree of biaxiality normal to the face was varied by making the specimens more or less thick. Accordingly, three types of specimens in various thicknesses were chosen: a shallow notch in which the concentration is primarily produced by the variable t/p, a deep notch in which the stress raiser is essentially a function of a/p and a medium notch in which both variables are of equal importance.

Due to the large number of specimens required for the tests it was decided to perform the main investigation with a series of impact bend specimens and to check the results with a series of tensile coupons.

Impact Specimens

A keyhole notched-bar type of specimen was employed which was slightly larger than the standard Charpy impact specimens to facilitate machining operations, Fig. 1. As mentioned previously, three different types of notches were designed to produce varying degrees of biaxiality in the notched section. The following are the parameters of the three types of notches:

Table 1—Notch Parameters

	Depth of notch t, *in.*	*Depth of section behind the notch* a, *in.*	*Radius* p	t/p	a/p
Shallow notch	0.44	0.500	0.023	1.91	21.7
Medium notch	0.113	0.500	0.035	3.23	14.3
Deep notch	0.435	0.500	0.038	11.4	13.2

To determine the effect of the thickness at the base of the notch the three types of notches were machined in four different specimen thickness of $T = {}^1/_{16}$, ${}^1/_8$, ${}^1/_4$ and ${}^1/_2$ in. Thus the following thickness to radius ratio was produced at the base of the notch:

Table 2—Thickness to Radius Ratio

	Radius, in.	*Thickness, in.*			
		${}^1/_{16}$	${}^1/_8$	${}^1/_4$	${}^1/_2$
Shallow notch	0.023	2.72	5.43	10.9	21.8
Medium notch	0.035	1.80	3.58	7.15	14.3
Deep notch	0.038	1.65	3.30	6.60	13.2

A second series of notched impact specimens was designed as a pilot investigation for the series of tensile coupons to follow. The double-notched coupon, Fig. 3 was chosen in three depths of notch. The specimen was impacted on one of the unnotched faces, thus producing on the opposite face a state of stress which was

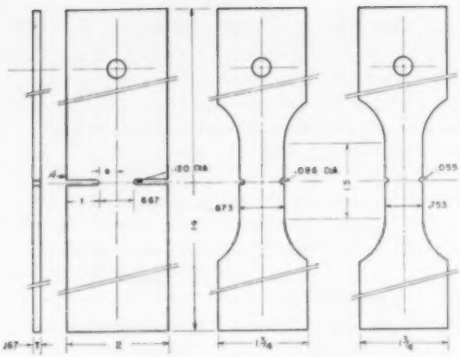


Fig. 4 Details of small tensile coupons

believed to simulate to some extent the stress state in the notched section of a very thin tensile coupon. The details of the notched section were scaled down in the ratio of 2:1 from the small tensile coupons.

Small Tensile Coupons

The series of tensile coupons, Fig. 4, have been included in this investigation as a spot check on the impact test. The notches were designed in the same manner as for the impact specimens, i.e., with a theoretical stress-concentration factor of three which was controlled by the variables t/p and a/p as in the impact specimens. The small tensile coupons were made in only one thickness $T = 0.167$ inches. The notch parameters were as follows:

Table 3—Notch Parameters of Tensile Coupons

	Depth of notch t, *in.*	*Depth of section behind the notch* a, *in.*	*Radius* p, *in.*	t/p	a/p	T/p
Shallow notch	0.043	0.333	0.0275	1.56	12.1	6.08
Medium notch	0.103	0.333	0.043	2.40	7.75	3.88
Deep notch	0.667	0.333	0.060	11.1	5.55	2.78

A photoelastic investigation has been performed* upon the tensile coupons to determine the elastic state of stress in the notched section and also to obtain a check of the theoretical stress-concentration factor. The stresses so determined are presented in Figs. 5 to 7. The maximum principal stress, in this case the longitudinal stress, is designated as p, and the transverse stress as q.

Large Tensile Coupon

One large coupon of the deep-notch type, which was scaled upward in the ratio of 4.5:1 from the smaller coupons was tested to obtain a spot check of the size effect phenomenon.

* See Appendix 2.

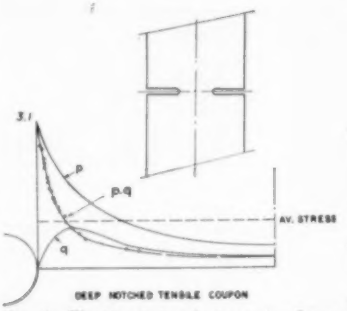


Fig. 5 Elastic state of stress in deep-notched tensile coupon as determined by photoelasticity

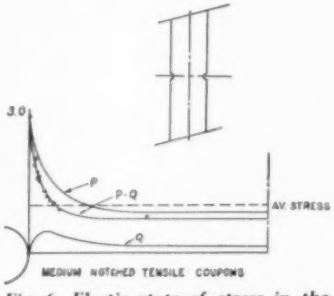


Fig. 6 Elastic state of stress in the medium notched tensile coupon as determined by photoelasticity

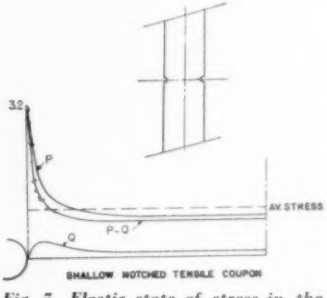


Fig. 7 Elastic state of stress in the shallow-notched tensile coupon as determined by photoelasticity

Table 4—Charpy Transition Temperatures

	A.S.T.M. A201A		−30° to −40° F.
	A.S.T.M. A285C		−24° to −32° F.
	Rimmed steel E		20° to −10° F.

Chemical Analyses/*

		C	*Mn*	*P*	*S*	*Si*	*Sn*	*Cu*	*Ni*	*Cr*	*V*	*Mo*	*N*
A201A	NS†	0.15	0.56	0.017	ND	0.21	0.015	0.12	0.07	0.02	0.001	0.002	0.006
	MT	0.12	0.55	0.015	0.029	0.22	0.015	0.08	0.08	0.04	0.001	0.001	0.006
A285C	NS	0.20	0.36	0.020	0.021	0.003	0.015	0.14	0.14	0.08	0.001	0.001	0.006
	MT	0.23	0.36	0.015	0.027	0.005	0.020	0.07	0.14	0.07	0.001	0.002	0.006
E	NS	0.20	0.40	0.014	0.035	0.03	ND	0.15	0.07	0.04	ND	0.013	0.006
	MT	0.20	0.40	0.014	0.036	0.03	ND	0.15	0.07	0.03	ND	0.012	0.006

* Obligingly communicated by A. E. Flanigan.
† NS = near surface, MT = mid thickness and ND = not determined.

MATERIAL AND PREPARATION OF SPECIMEN

The primary steel used in the impact investigation was A.S.T.M. A201A, firebox quality steel from the Kaiser Fontana mill. To determine the effect of a change in material a second steel A.S.T.M. A285C was tested. A third steel, rimmed steel "E" was procured from the U. S. Coast Guard for the tensile tests. The transition temperatures as indicated by the standard keyhole notch Charpy specimen and the chemical analyses of the three steels are as shown in Table 4.

In the machining of the specimens special care was taken to insure uniformity. All flat surfaces were ground by a surface grinder with coolant to prevent overheating the material. The notches were formed by jig drilling then sawing into the hole and then filing the slot tangent to the diameter.

For all specimens the notched section was perpendicular to the direction of rolling, and the notch was drilled in the thickness direction of the plate. In the machining of the small tensile coupons the material was removed equally from each side of the plate. Thus, the material of the specimen was that of the core of the rimmed plate. The large coupon was cut from the $^3/_4$-in. stock with no machining operations performed on the face of the coupon.

EXPERIMENTAL PROCEDURE

Impact Specimens

The impact specimens were tested at temperatures ranging from room temperature to $-200°$ F. in a standard 110 ft.-lb. Charpy-impact machine equipped with modified jaws to accommodate the increased length of the test pieces. A simple bath of dry ice and alcohol was used to cool those specimens tested above $-90°$ F. Below $-90°$ F. the specimens were cooled in a simple bath of petroleum ether refrigerated by passing liquid nitrogen through a coil submerged in the ether. The temperature at impact was determined as follows: a thermocouple was imbedded in a dummy specimen, which was similar to the test specimens and immersed in the bath with them. For each specimen tested a record was made of the temperature of the dummy specimen as well as the time required to place and impact the specimen in the testing machine. The temperature of the testpiece was then determined by correcting the temperature indicated by the dummy for the temperature rise incurred in placing the testpiece, as computed from the experimental heating curves.

The energy absorbed at failure was recorded for all specimens, but, in order to establish two independent criteria for the transition temperature, for several series

Fig. 8 Experimental setup for recording deformation and load on a double-channel brush oscillograph

Specimen equipped with a special clip gage

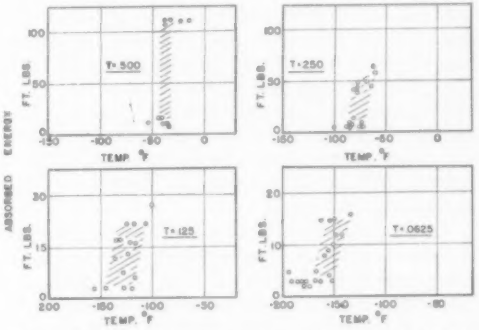


Fig. 9 Deep-notch impact results. Steel A.S.M. A201A

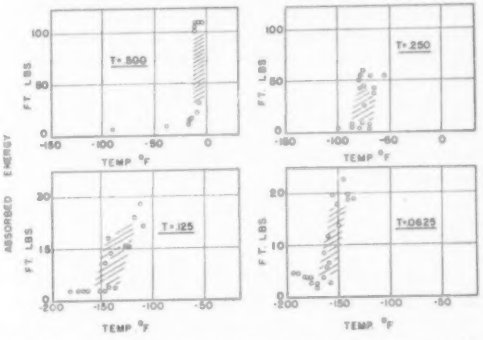


Fig. 10 Medium-notch impact results. Steel A.S.M. A201A

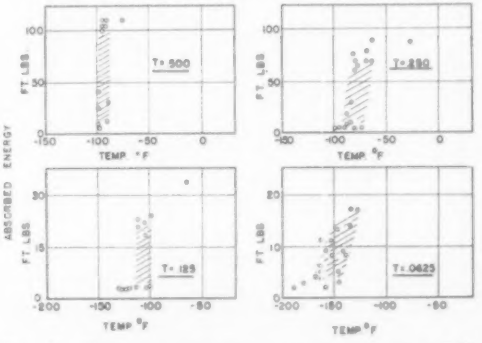


Fig. 11 Shallow-notch impact results. Steel A.S.M. A201A

of specimens the per cent thickness contraction at the base of the notch also was recorded.

Small Tensile Coupons

The small tensile coupons were cooled by a liquid-nitrogen spray apparatus while in place in the 60,000-lb. Baldwin testing machine. The apparatus consisted of a small tank enclosing the notched section into which a stream of liquid nitrogen was directed on the specimen 1 in. above the notched section and collected 1 in. below the notched section. The small tank was formed from aluminum of sufficient thickness ($^1/_4$ in.) for the heat to be extracted from both faces of the specimen. In this manner a more nearly uniform temperature distribution in the notched section was produced. The indicated temperature was measured by a thermocouple imbedded at the edge of the coupon at point *A*, Fig. 4. Reference is made to the Appendix 1 for the correction of the indicated temperature and the experimentally determined temperature distribution in the notched section.

As in the case of the impact specimens, two independent criteria for the determination of the embrittlement temperature were established: the per cent thickness contraction at the notch and the deformation across the notched section, measured in the longitudinal direction. A special clip gage was used for the latter purpose, Fig. 8. The deformation was recorded on a double-channel brush oscillograph simultaneously with the load, which was picked up by a calibrated strain gage link. The per cent thickness contraction was measured to an accuracy of 0.001 in. by a traveling microscope. The strain rate in the elastic range, averaged over the notched cross section, was about 10^{-4} per second.

Large Tensile Coupon

The large tensile coupon was cooled in place in the 200,000-lb. Baldwin testing machine by a liquid-nitrogen spray apparatus, patterned after the unit developed at the University of California at Berkeley.* The liquid nitrogen was forced through the spray lines by controlling the pressure in the Dewar flask with a bottle of pressurized dry nitrogen and a mercury manometer. Only one coupon was tested; therefore the so-called Shepler technique[11] was employed to obtain the transition temperature. That is, the test was initiated at $-95°$ F. with the coupon being loaded until a departure from the straight line was noted in the load deformation recording which was made in the same manner as for the small tensile coupons. Each time the deformation curve was noted to depart from the straight line, the load was removed and the temperature lowered approximately 20° F. After seven such loading cycles the specimen was fractured at $-221°$ F.; this temperature coincided with the transition temperature previously determined for the small tensile coupons. The rate of straining was about $^1/_4$ of that used for the small coupons.

RESULTS OF TESTS

Impact Tests

The results of the impact specimens machined from the A.S.T.M. A201A steel have been plotted in Figs. 9 to 11 with the energy absorption and the temperature as variables. As a check of the transition temperature indicated by the energy absorption, the per cent thickness contraction at the base of the notch has been plotted for one thickness of specimen in Fig. 12. The results of the series of specimens prepared from A.S.T.M. A285C steel is presented in Fig. 13. For the purpose of comparison, the mean zone of scatter, shown in the figures as the hashed zone, has been taken as the transition temperature. It is seen by comparing the upper left-hand plots in Fig. 9 to 11 with the plot, Fig. 12, that the per cent contraction and energy absorption criteria are equivalent. The impact results for the A285C steel, Fig. 13, are shifted toward higher temperatures, as could have been anticipated from the

* We are indebted to Prof. Boodberg for the sketches of the apparatus.

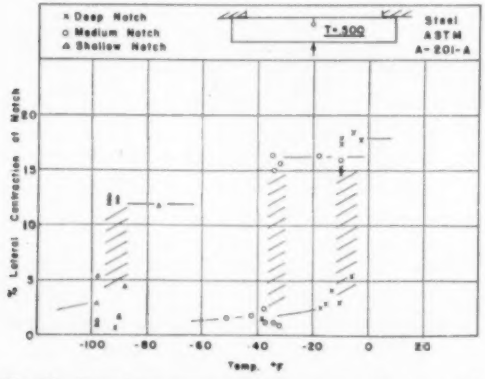


Fig. 12 Transition temperature by contraction at notch

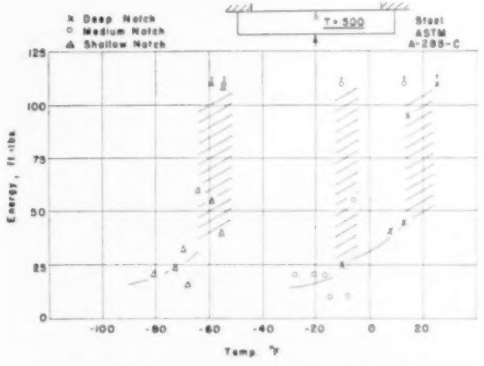


Fig. 13 Impact results of A-285-C steel

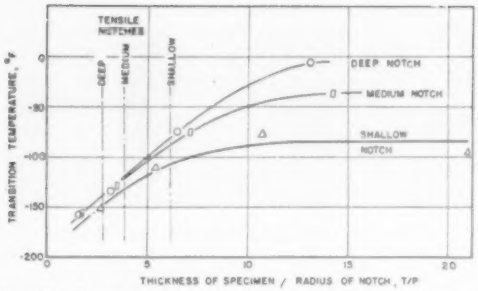


Fig. 14 Comparison of transition temperatures of impact specimens

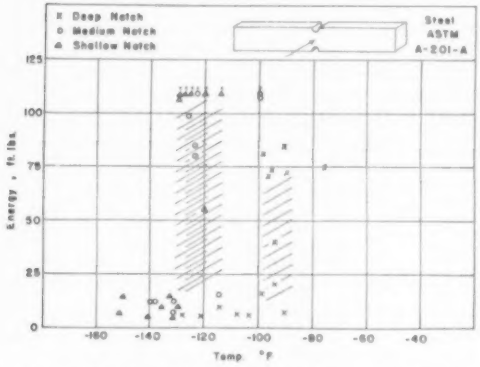


Fig. 15 Results of double-notched impact specimens

Charpy impact results, Table 4, but the shift is the same for the three types of notches. Thus the effects of the notch geometry are the same for the two types of steel. To facilitate comparison between the various types of notches, the transition temperatures for the A201A steel have been replotted against a reduced variable, T/p, Fig. 14, where T is the thickness of the specimen and p is the radius of the notch. The significance of this plot will be discussed subsequently. The results for the series of double-notched impact specimens machined according to Fig. 3 are shown in Fig. 15. By comparison with Fig. 14 it is seen that the transition temperatures are less widely separated and that they are shifted toward much lower values. As pointed out previously this series was used as a pilot investigation for the tensile tests to follow. On the strength of the results obtained it was concluded that because of a much slower rate of straining the tension tests must be made with a much more brittle type of steel, viz., a rimmed steel, in order to contain the transition temperatures within workable limits.

Tensile Tests

A plot of the load vs. the average longitudinal deformation as recorded across the notched section of the small tensile coupons is presented in Figs. 16 to 18. The per cent thickness contraction at the base of the notch was also measured and is shown in Fig. 19. Figure 20 gives the average true-fracture stress, i.e., the load at failure divided by the area of the section after failure. All of the fractures below − 150° F. were entirely of a granular or cleavage nature. Three small coupons of the deep-notch type were broken between − 80 and −100° F. with 20% failure by shear and 80% by cleavage, Fig. 21.

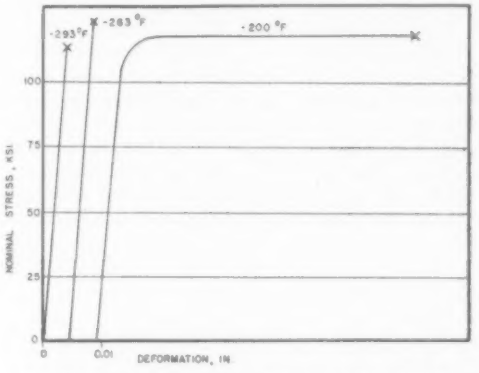


Fig. 16 Load-deformation of deep-notched tensile coupons

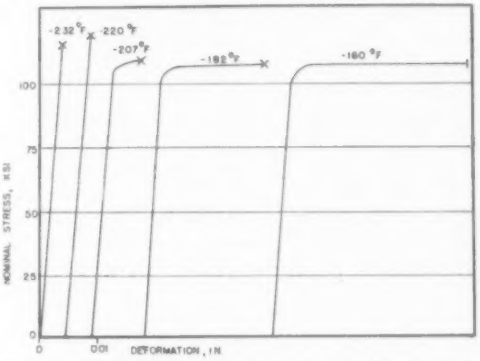


Fig. 17 Load-deformation of medium-notched tensile coupons

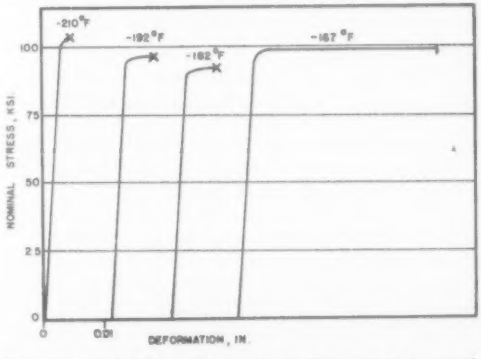


Fig. 18 Load-deformation of shallow-notched tensile coupons

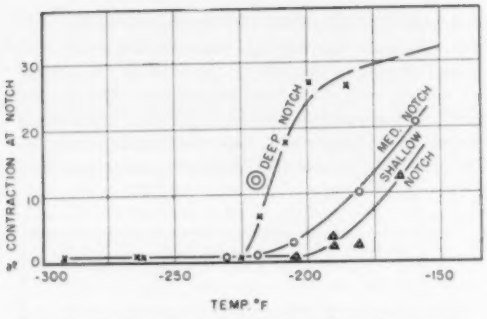


Fig. 19 Contraction at notch of small tensile coupons

The load vs. the average longitudinal deformation as recorded across the notched section of the large-tensile coupon, is shown in Fig. 22. The per cent thickness contraction at the base of the notch has been repre-

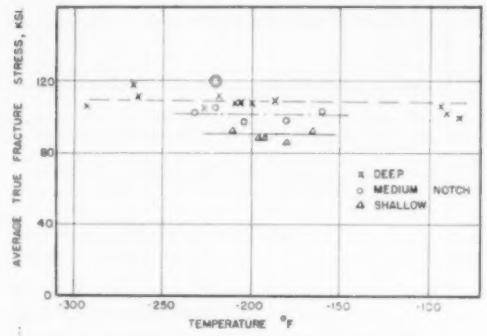


Fig. 20 Fracture stress of small tensile coupons

sented by two concentric circles on the contraction-temperature plot for the small specimens, Fig. 19. The fracture stress as defined above has been shown for the large specimen in Fig. 20, also as two concentric circles.

DISCUSSION

The discussion of the results is facilitated by the introduction of the concept of the flow and fracture curves.

The Concept of the Flow and Fracture Curves

A material is said to be notch brittle or notch sensitive if at a certain temperature it can break with a granular or cleavage type of fracture when it contains a notch, while exhibiting a fibrous or ductile fracture in the ordinary tensile test. The first successful theory of notch brittleness was advanced by Ludwig, which has since been refined by Davidenkov and later Orowan.[2] According to this theory there exist two different phenomena: the fibrous ductile fracture for which no strength or strain criterium has been found yet, and the brittle fracture for which there is an explanation based

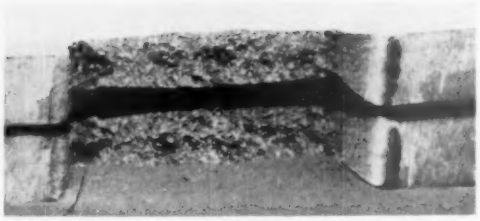


Fig. 21 20% shear, 80% cleavage failure

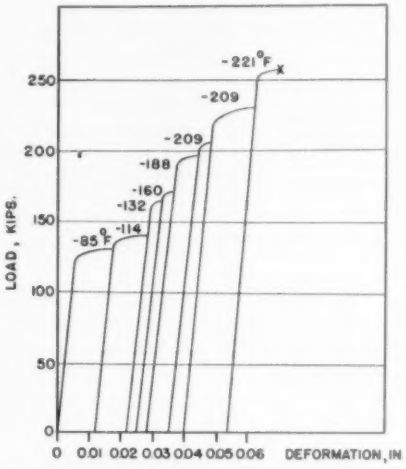


Fig. 22 Load-deformation of large tensile coupon

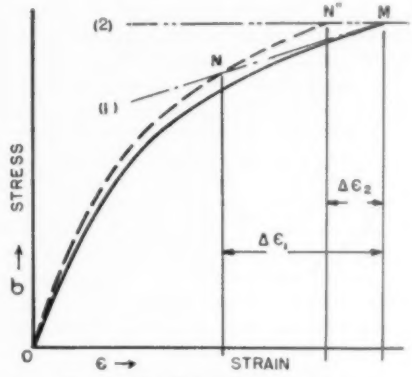


Fig. 23 The flow and fracture curves

on the concept of the fracture and flow curves, Fig. 23. The fracture curve represents a relationship between the maximum normal stress and strain for which the material fails in a brittle manner, the flow curve a relationship for which plastic deformation occurs. The energy absorbed at failure will depend on the values of stress and strain at which these two curves intersect. The factors affecting the flow curve can be experimentally investigated. It has been found that in general

the ductility decreases, i.e., smaller deformation correspond to the same value of stress as the following factors increase:

1. the amount of previous deformation (strain hardening),
2. strain rate,
3. complexity of the state of stress, and
4. as the temperature decreases.

The factors affecting the brittle fracture cannot be investigated directly, but on the basis of theoretical considerations[2] there are reasons to believe that the fracture curve is much less sensitive to external influences than the flow curve.

In the case of mild steel the occurrence of the ductility transition temperature may be explained[1] by assuming that the slope of the fracture curve is very nearly the same as that of the flow curve. On this assumption a small change of any of the aforementioned factors can cause an upward trend of the flow curve of a sufficient magnitude to produce an appreciable change in the amount of deformation at fracture. This situation is illustrated schematically by means of Fig. 23. See also reference.[16]

Impact Tests

The impact tests were designed to investigate the effect of a complex stress field as produced by constraint in a notched-bar impact specimen. The elastic state of stress existing across the width of the notched section of the tensile coupons has been presented previously in Figs. 5 to 7. The biaxial-stress ratio of the transverse stress due to the depth of the notch to the longitudinal stress has been presented in Fig. 24. The biaxiality in the region near the notch due to bending may be assumed to be the same on the basis of published photoelastic data.[6]

It may be seen from Fig. 14 that as T/p tends to zero the three types of notches approach the same transition temperature. Thus the degree of biaxiality as given by Fig. 24 appears to have no influence on the brittleness at this limit. On the other hand, the biaxiality at the base of the notch in the thickness direction, which is very small in the thin specimens, is known to approach a value of 0.5 as the thickness increases.[1] However, at this limit the transition temperatures approach different asymptotic values for the three types of specimens, the deeper notches having higher transition temperatures, i.e., greater brittleness than the more shallow ones. Since the depth of the notch is associated with a higher biaxiality in the plane normal to the thickness, it must be inferred that the combination of the two biaxialities, one in the direction of thickness and the other in the plane normal to it, produces a triaxial stress field at some distance behind the notch, which enhances the embrittlement. This situation is further clarified by Fig. 25 in which the transition temperatures have been replotted from Fig. 14 as a function of the ratio t/a, where t is the depth of the notch and a is the depth of the material behind the notch.

However, if the triaxiality is to have an effect upon the embrittlement, the fracture must initiate at some point behind the notch. The most logical point is the point of maximum triaxiality. Otherwise, the transition temperatures of the three notches should all be on one curve, which would be affected only by the increase in thickness.

Tensile Tests

As indicated previously, the series of tensile tests have been included in this investigation as a check of the impact results. The results of the small coupons will be discussed first.

As may be seen in Fig. 19, the transition temperature of the deep-notched coupon is lower than that of the shallow-notched one. At first this seems a contradiction to the impact results. However, if the values of T/p for the tensile coupons are plotted on the curve of transition temperatures for the impact specimens, Fig. 14, it is seen that the tensile results are in the correct

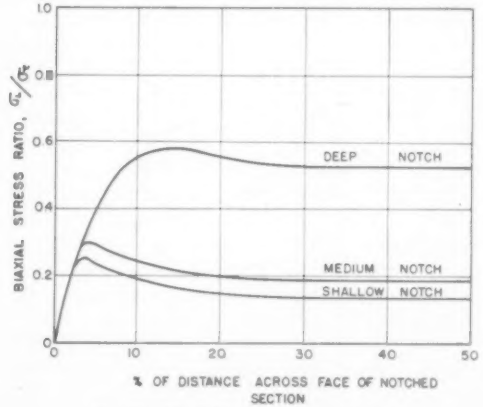


Fig. 24 Biaxiality of tensile coupons

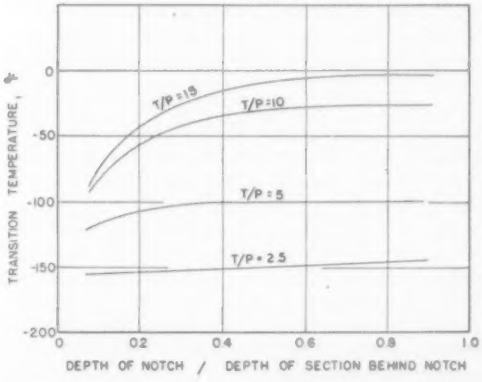


Fig. 25 Transition temperature vs. depth of notch

relationship, emphasizing the effect of the ratio of T/p even on very thin coupons.

The average fracture stress as defined by the load at fracture divided by the area after fracture is shown for all tensile coupons in Fig. 20. The variation of temperature causes no apparent change in the average stress,* but there does seem to be a difference in the stress between the three types of notches. This difference may be explained in the following way:

The fact that the more shallow-notched specimens possess higher transition temperatures than the more deep-notched ones seems to indicate a higher degree of triaxiality near the notch, presumably because of a higher T/p ratio. But this triaxiality falls off more rapidly toward the center of the specimen as the notch is more shallow. As a result the distribution of stress at the moment of (brittle) fracture is also less uniform. As the value of the (local) fracture stress is assumed to be the same in all three cases, the average stress for the more shallow-notched specimens must be lower than for the more deep-notched ones.

Two specimens fractured at $-90°$ F., failed with an 80% cleavage fracture, the 20% zone adjacent to the notch being ductile in nature. This type of fracture may have been produced in two ways: (1) the fracture may have been initiated by the exhaustion of ductility in the area near the notch, and then due to the rate of propagation and the high-stress concentration factor at the head of the crack, the fracture has become of the cleavage type; (2) the fracture may have been initiated behind the notch and propagated toward the center in a brittle fashion, and toward the base of the notch in a ductile fashion. Previously it has been pointed out that there is good theoretical reason for the fracture to be initiated behind the notch. It will be now shown, following the ideas by Vanderbeck and Gensamer[3], that it is also possible for the two types of fracture to stem from the same area. To this effect reference is made to the schematic diagrams, Figs. 26 and 27. Figure 26 represents a family of maximum stress-maximum strain diagrams (flow curves) with a transition from ductile (point C) to brittle (point B) fracture as the degree of triaxiality increases. Figure 27 shows an assumed distribution of maximum stress and maximum strain in the notched section at fracture. This distribution is consistent with the experimental findings for small plastic deformations.[12, 13] At the point of initiation of crack, point A, the longitudinal stress will be at the maximum by virtue of a more complex stress field. Assuming that the corresponding point on the stress-strain diagram is at B, it is seen that to the right of A ($A+\Delta$) the stress-strain relationship will be represented on Fig. 26 by some point $B+\Delta$ which is to the left and below point B, while to the left of A ($A-\Delta$), the stress-strain relationship will be given by some point $B-\Delta$, which lies below and to the right of B. As the crack spreads, the stress field at $A+\Delta$ may become even more complex than at A, because of the sharpness of crack,

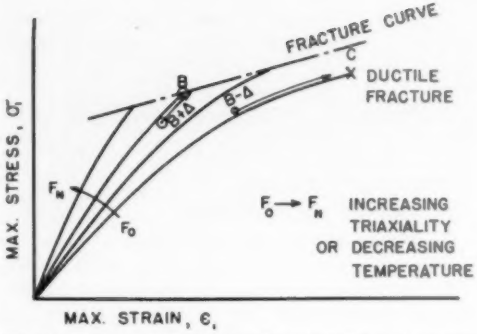


Fig. 26 Flow curves influenced by triaxiality and temperature (schematic)

while that at $A-\Delta$ becomes much less complex (14). Consequently $B+\Delta$ moves upward with little increase of strain which causes a brittle type of fracture behind (to the right of) A, while $B-\Delta$ moves upward with large increase of strain, which causes a ductile fracture near the notch.

As the temperature is lowered the flow curves move from F_o to F_n. As a result, there is first the disappearance of the shear type of fracture, then a rapid decrease of deformation, Fig. 1. Conversely, an increase of temperature causes the flow curves to move from F_n to F_o with the ensuing increase of deformation, until the point $B+\Delta$ is no longer capable of intercepting the fracture curve, whereupon the whole section exhibits the shear type of fracture. In this manner the two distinct transitions pointed out by Vanderbeck and Gensamer are observed, viz., the ductility transition at a lower temperature and the fracture transition at a higher temperature.

These two transitions have not been observed separately in the bend impact test, presumably because of the steep stress (and strain) gradient behind the notch, which restricted the absorption of energy to a very narrow area as long as the point B remained on the fracture curve, Fig. 26. The same behavior might be expected in tension, if the specimen had a very sharp notch.

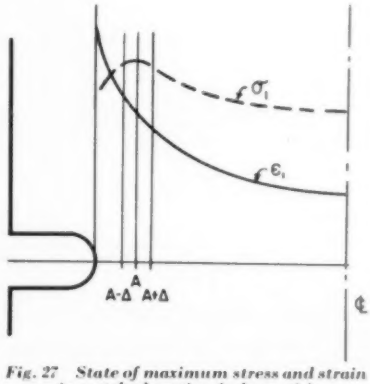


Fig. 27 State of maximum stress and strain in notched section (schematic)

* Possibly because the effect of a higher temperature is offset by that of a higher deformation.

One specimen of the large deep-notched tensile coupons was tested to obtain a spot check of the size effect phenomenon. Although the use of the Shepler technique described previously may be objected to on various grounds, this technique would not mask any phenomenal difference in the two sizes of specimens. The average fracture stress was very nearly the same as that obtained with the smaller coupons, and the per cent thickness contraction at the notch agreed very well with that of smaller coupon tests at the same temperature, Fig. 19.* The size effect as predicted by statistics is probably present, however, this could not be demonstrated by the test of only one specimen. On the faith of this test it appears that the size effect, if correctly accounted for, would not be of great importance in the phenomenon of notch embrittlement.

CONCLUSIONS

On the basis of the experiments reported herein it is possible to draw the following conclusions in regard to the embrittlement of mild steel due to notching:

1. In addition to the two factors reported in the literature, viz., the stress concentration and the degree of biaxiality in the thickness direction of the specimen, a third factor must be considered, namely the degree of biaxiality on the face of the specimen, or briefly the biaxiality transverse to the notch.

2. Using the raise of the transition temperature as an index of increasing brittleness, it is found that when the last mentioned factor is superimposed on the two previously mentioned the transition temperature can be raised by as much as 90° F., which puts the zone of brittleness of the particular mild steel used in the range of the atmospheric conditions.

3. The effect of the biaxiality transverse to the notch depends on the existence of the biaxiality in the thickness direction. Thus, this effect tends to disappear as the thickness of the specimen tends to zero. It is therefore concluded that the increase of brittleness produced by the additional biaxiality is, in reality, caused by a triaxial stress field behind the notch.

4. If the effect of triaxiality is the predominent factor of brittleness, the failure should initiate at some point below the surface of the notch. Although the experimental evidence of an internal crack has not been obtained, the occurrence and type of failures is consistent with this statement.

5. In the light of the present studies the strain rather than stress concentration factor should be used in describing the notch brittleness of steel. Further studies however are needed to clarify the significance of this factor.

6. It appears reasonable to anticipate a range of brittleness in weldments at least as wide as that obtained in the present studies, depending on the type of joint. This conclusion is in qualitative agreement with the available data, but so far as known it has not been corroborated by systematic studies.

* The fact that the rate of straining was four times smaller would make this agreement even better since it would shift the point about 15° F. to the right according to the available information.

ACKNOWLEDGMENTS

Acknowledgment is made to the Welding Research Council without whose financial assistance this project could not have been undertaken.

Special assistance in the procurement of the steel was rendered by Dr. Nash of C. F. Braun, Inc., Dr. F. Jonassen of the National Research Council and Dr. A. E. Flanigan of the University of California, Los Angeles.

The preparation of the specimens was performed in the Machine Shop, Department of Engineering, under the direction of H. Showman and H. Abbott.

Appendix I

TEMPERATURE DISTRIBUTION AND CORRECTION OF THE INDICATED TEMPERATURE IN TENSILE SPECIMENS

Because of the mode of cooling it was necessary to check the temperature distribution in the tensile coupons. To this end a dummy tensile specimen with thermocouples embedded at various points was run through the range of the testing temperatures. The thermocouples were made of No. 30 iron-constant wire. They were forced into small holes drilled in the specimen, and the contact with the latter was insured by peening the metal around the thermocouple junction. In the case of the deep-notched specimen, eight thermocouples were employed: three in the notched section and five outside this section, Fig. 28. The thermocouple at *A* was used to obtain the temperature actually indicated in the tensile specimens. In the case of the shallow- and medium-notched specimens only one thermocouple was placed outside the notched area, viz., at *B*, Fig. 28 to record the indicated temperature in actual testing. As might be anticipated the least uniform distribution of temperatures in the notched section was obtained in the deep-notched specimens. The discrepancy between the center and the edge amounted to +10° F. at −240° F., Fig. 28, but was considerably less at higher temperatures as can

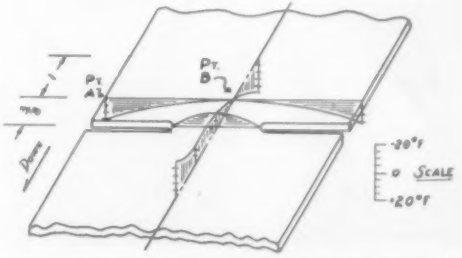


Fig. 28 Location of thermocouples and temperature distribution in the deep-notched coupon at − 240° F.

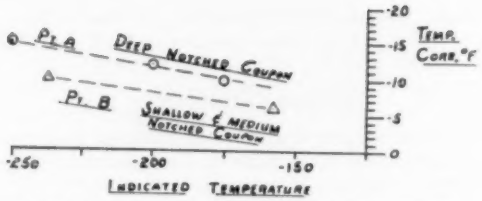


Fig. 29 Correction of the indicated temperatures

be inferred from Fig. 29. This last figure also shows the correction which had to be applied to the indicated temperature in order to obtain the temperature at the bottom of the notch.

Appendix II

PHOTOELASTIC STUDY OF STRESS CONCENTRATION AND BIAXIALITY*

The purpose of this study was to check the validity of Neuber formula for stress concentration and to determine the degree of biaxiality in the notched section. Models duplicating the three types of tensile specimens, Fig. 3, were made of plastic CR-39 and analyzed in a diffusion light polariscope.† The results are plotted in Figs. 5 to 7. The lines marked p and q have been drawn through experimentally determined points using fringe patterns under various loads, such as shown in Fig. 30. The lines marked p and q have been obtained by the so-called slope equilibrium method.‡ They represent: p, the plot of longitudinal stress, and q, the plot of transverse stress across the notched section. It is seen that:

1. The experimentally determined stress-concentration factor, i.e., the ratio of the longitudinal stress at the notch to the average longitudinal stress in the notched section = 3 (± 0.2) for all three models. This result is in agreement with Neuber's stress concentration formula.

2. The degree of biaxiality as measured by the ratio p/q, Fig. 24, rises very rapidly to a maximum at a short distance from the notch and then falls off gradually toward the center line. The maximum value of biaxiality is:

0.58 for the deep notch
0.30 for the intermediate notch
0.23 for the shallow notch

Thus, there is a marked difference in the degree of biaxiality between the deep and the shallow notched specimens.

* Performed by A. Eshleman and T. Herrmann, senior students in the Department of Engineering, University of California, Los Angeles.
† Cf. A. J. Durelli, S.E.S.A. Vol. VI, No. 1.

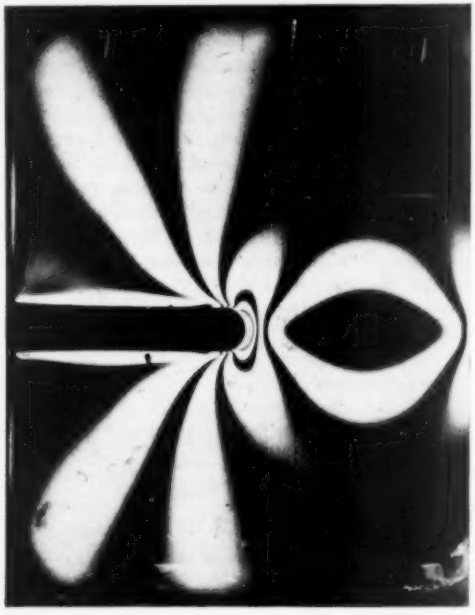


Fig. 30 Fringe pattern in the deep-notched photoelastic model of the tensile specimen

Appendix III

STUDY OF LOCAL DEFORMATION BY MEANS OF X-RAYS*

An attempt was made in this study to evaluate the amount of local plastic deformation at and below the transition temperature using as a criterion the X-ray diffraction line broadening. To this end three deep-notched tensile specimens, Fig. 4, were treated to yield uniform and sharp diffraction lines in the virgin, undeformed condition. Thereupon they were fractured as specified in Table 5.

From the per cent contraction at the notch it would appear that specimen C was at, or slightly above the transition temperature, while specimens A and B were well below this temperature. The fractured areas were

* Performed by H. Baer, graduate student with the assistance of W. E. Larson, senior student, Dept. of Engineering, University of California, Los Angeles.
‡ Cf. M. M. Frocht, Photoelasticity Vol. 1, 1941.

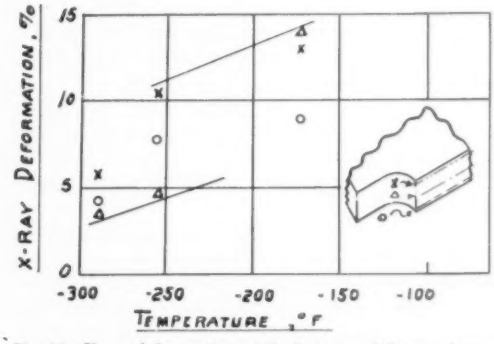


Fig. 31 X-ray deformation at the bottom of the notch as a function of temperature

Table 5—Tension Tests of X-ray Specimens

Specimen	*Temperature*	*Contraction at notch, %*	*Load at fracture, lb.*	*Remarks*
A	−290	0.6	10,800	Partial bending
B	−245	0.9	9,700	Partial bending
C	−173	4.7	13,260	

then explored locally by means of a narrow X-ray beam (about $^1/_{16}$ in. in diameter) at three points at the bottom of the notch, Fig. 31, and at three points of the mid-thickness distant 0.03, 0.06 and 0.33 in. from the notch, Fig. 32. Back reflection diagrams of the (310) doublets were taken using Co unfiltered radiation. The films were microphotometered along the diameter that was parallel to the smallest dimension of the target, and the degree of line broadening was determined separately at each end of this diameter by a procedure explained elsewhere.* With two exceptions the determinations made at both ends of the diameter agreed to better than 10%. The average degree of line broadening at each point was then compared to a set of values obtained on a similarly treated standard tensile specimen after the latter had undergone various amounts of deformation ranging from 0 to 14% natural strain. From the above comparison the equivalent amount of deformation was determined by interpolation for each point of the fractured area to within 2% natural strain. For brevity this amount will be called "X-ray deformation."

Figure 31 shows the X-ray deformation measured at three points at the bottom of the notch as a function of temperature, while Fig. 32 gives the X-ray deformation at the mid-thickness of the specimen as a function of the distance from the notch. Because of the large probable error, only the general trend of the diagrams is significant. This trend is in agreement with that found from macroscopic measurements, but the value of deformation is much higher. This is not surprising considering that the deformation becomes more and more localized as the fracture tends to assume a more brittle character. It is worth noting that even at −290° F. there is a nonnegligible amount of plastic deformation as revealed by the X-ray studies.

* Rosenthal, D., *Journal of Applied Physics*, Vol. 20 (12), 1257 (1949).

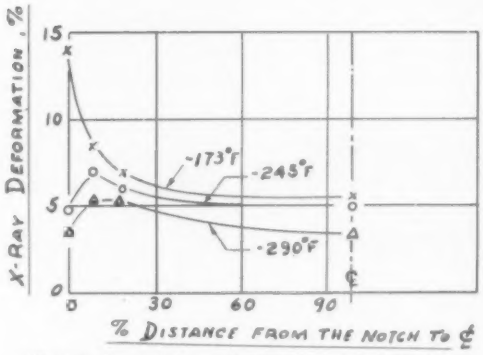


Fig. 32 X-ray deformation at the notched section

References

1. Holloman, J. H., "The Notched Bar Impact Test," The Welding Journal, **24** (4), Research Suppl., 230-s to 244-s (1945).
2. Orowan, E., "Notch Brittleness and the Strength of Metals," Glasgow (1945).
3. Vanderbeck, R. W., and Gensamer, M., "Evaluating Notch Toughness," The Welding Journal, **29** (1), Research Suppl., 37-s to 48-s (1950).
4. Stout, R. D., and McGeady, L. J., "The Meaning and Measurement of Transition Temperature," *Ibid.*, **27** (6), Research Suppl., 299-s to 302-s (1948).
5. Maurer, E., and Mailander, R., "Zur Frage der Blausprodigkeit," *Stahl und Eisen*, 45, 409 (1925).
6. Frocht, M. M., *Photoelasticity*, John Wiley & Sons, New York, 1941.
7. Neuber, H., *Theory of Notch Stresses*, J. W. Edwards, Ann Arbor, Mich., 1946.
8. Gensamer, M., "Strength of Metals Under Combined Stresses," Cleveland, 1941.
9. MacGregor, C. W., and Grossman, N., "A Comparison of the Brittle Transition Temperatures as Determined by the Charpy Impact and the M.I.T. Slow Bend Tests," The Welding Journal, **27** (1), Research Suppl., 16-s to 19-s (1948).
10. Brewer, G., "Biaxial Stresses in Rigid Vessel Simulated in Notched Tensile Coupon," *Metals Progress*, **51** (1), 91 (1947).
11. Shepler, P. R., "DeForest Brittle Temperature Research," The Welding Journal, **25** (5), Research Suppl., 321-s to 332-s (1946).
12. Stowell, E. Z., "Stress & Strain Concentrations at a Circular Hole in an Infinite Plate," NACA, TN 2073.
13. Norton, J. T., Rosenthal, D., Maloof, S. B., "X-Ray Diffraction Study of Notch Bend Test," The Welding Journal, **25** (5), Research Suppl., 269-s to 276-s (1946).
14. Sachs, G., and Lubahn, J., "Effects of Notching on Strained Metals," *The Iron Age*, **150** (15), 31 (1942).
15. DeGarmo, E. P., Meriam, J. L., and Grassi, R. C., "Some Tests of Large Welded Structures," The Welding Journal, **22** (5), Research Suppl., 257-s to 267-s (1947).
16. McAdam, D. J., Jr., "The Fracture Stress of Metals as Affected by Plastic Deformation, the Stress System, and Size, Cold Working of Metals," *American Society for Metals*, 321 (1949).
17. Grossman, Nicholas, "Pearlitic Structure Effect on Brittle Transition Temperature," The Welding Journal, **28** (6), Research Suppl., p. 265-s to 269-s (1949).

Interpretive Report, Fabrication Division, Pressure Vessel Research Committee

An interpretive engineering report of contemporary scientific research in the fabrication of pressure vessels and closely allied fields

by H. C. Boardman

FOREWORD

THE Fabrication Division pledged itself to try to tell the engineer, in his own language, what has been found out about the effects of fabrication on steel, what the findings mean, and how to use them. This will be hard to do; first, because much that will be reported has been partly known for a long time, hence cannot be ascribed to specific sources, and is drawn not from the Division's records alone but also from allied Welding Research Council projects, pertinent contemporary literature, and, perhaps most important of all, the whole background of pressure vessel experience; second, because it is difficult to relate laboratory results to actual structures and translate them into shop instructions and code rules; third, because many factors are involved in complex ways which are not well understood; and, fourth, because the engineer, in order to appreciate and apply the knowledge gained must learn to think of welded structures in terms of localized (ductility, toughness, restraint and temperature) as well as he has been thinking of them in terms of general (elasticity and strength).

BACKGROUND OF EXPERIENCE

When pressure vessels were wholly riveted, fabricators already knew that steel is changed by cold forming; that flanging, braking, rolling, pressing and dishing increase the yield point and reduce the ductility; that cold steel is easier to crack than warm steel; that fractures in service are generally brittle although the steel invariably is ductile in the conventional tension tests; and that stress sometimes promotes corrosion.

Welding really came of age in the decade prior to World War II. Behind its growth were men of energy, faith and vision, who dared more than they knew. Like most lusty infants welding for a time seemed largely immune to major ills. Thousands of welded pressure vessels were made—many with bare electrodes. They were hammer tested under nearly yield-point pressure. If they endured this ordeal they were considered fit for use and, in general, proved to be so. Cracks occurred in service but most of them stopped not far from their origins or grew slowly thus fostering the comforting idea that they merely relieved localized overstress and seldom extended much beyond the regions of such stress.

During the War there developed an epidemic of cracks in welded pressure vessels and in welded ships, more in winter than in summer. Probably this fracture flurry was the result of a combination of substandard (steel, design, fabrication including welding, and inspection.)

That the steel may have been below par is implied by the following excerpts from a paper on "Steel Compositions and Specifications," by Charles M. Parker, Secretary, Committee on Manufacturing Problems, American Iron and Steel Institute, which appeared in March 1949, as the No. 1 issue of the Welding Research Council Bulletin Series:

"The steel industry of the United States now leads the world in production and technology. Until recent years, its growth was stimulated and nourished by the discovery and use of high-grade iron ores, excellent metallurgical coking coals and a plentiful supply of good iron and steel scrap.

"The unprecedented production of iron and steel in recent years has depleted our reserves of high-grade raw materials to such an extent that the known remaining materials are either inferior in quality or remote from established centers of steel production. The inferior quality of these raw materials imposes difficult technological problems, some of the consequences of which may have to be passed on to consumers of steel either temporarily or permanently, depending upon their successful solution and economic application."

Doubtless some of these consequences rightfully were

H. C. Boardman is Director of Research, Chicago Bridge & Iron Company, Chicago, Ill.

This report is based on ideas and suggestions received from members of a Committee of the Fabrication Division, P.V.R.C. of the Welding Research Council consisting of P. R. Cassidy, J. Earthman, Jr., W. P. Gerhart, B. G. Johnston, F. L. Plummer, Walter Samans and W. Spraragen.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

passed on to consumers under the urgency of war and so contributed to the aforesaid epidemic of cracking which harassed both fabricators and users but, as a rule, did not cause complete failures.

There were several tragic exceptions; out of roughly 5000 welded ships about 3% ruptured sufficiently to endanger or destroy the vessels; and one large carbon-steel welded pressure vessel, out of the many that were made, is known to have failed completely in service. The brittle, rapid and extensive fractures in normally ductile material, which characterized each of these failures, shocked and puzzled the engineering world; ushered in the era of "transition temperature" (very roughly the temperature above which a given piece of steel, or a steel assembly, fails in a generally ductile manner when loaded in a certain way, and below which it fails in a generally brittle manner when loaded in the same way), seldom heard of before the war when "locked-up stresses" and "stress gradients" were the vogue; rudely ended the complacent view that cracking was only benign; and prompted intensive searches for, and studies of, the factors contributing to brittle fracture. Fabricating operations were known to be among these factors and their investigation became the task of the Fabrication Division.

Although the Division never said so officially, its work was prompted by these ship and pressure vessel failures of the war period plus the well known but disturbing facts that steels ordered to the same A.S.T.M. Specification and intended by the mill to be alike, sometimes differ widely in their reactions to fabrication and service conditions and that makers and users of pressure vessels, and writers of code rules for pressure vessels, have long tacitly assumed that, no matter what measures are found necessary to produce a sound welded vessel by accepted standards, and regardless of cracks discovered and repaired during fabrication, any vessel which survives the prescribed tests has left sufficient toughness to perform satisfactorily in service; for example, the A.S.M.E. Unfired Pressure Vessel Code has no restrictions on cold rolling, thus implying that cold rolling within the Code limits on thickness for nonstress relieved vessels, and provided it causes no cracking, leaves a sufficient reserve of ductility to provide safely for welding, testing and service conditions of loading, restraint and temperature.

SCOPE, PURPOSE AND PHILOSOPHY

The scope, purpose and general philosophy of the Division's work are aptly expressed in the following statement by Dr. Kanter which is part of the minutes of the June 20, 1946, meeting of the Division.

"This letter is written for the purpose of setting forth the reasons for undertaking the carbon-steel plate investigations as they were presented at the first meeting.

"As the writer understands the scope of the Fabrication Division researches they should encompass, among other things, consideration of all mechanical and thermal operations done on steel from the time it is received from the mill until it is ready for service as pressure vessels. In undertaking such researches, it is obviously apparent that the steels upon which such mechanical and thermal operations are performed may not be uniform in their responses to fabrication operations and must, therefore, be carefully defined. It has become furthermore apparent, through some of the experiences which have culminated in the organization of the Pressure Vessel Research Committee, that the ordinary commercial steel specifications, under which the materials for pressure vessel fabrication are procured, do not adequately define, restrict and control some of the properties which must be considered in the mechanical and thermal operations influencing successful and dependable fabrication.

"In order to establish a basis for procuring test steels which will demonstrate the influences of variables uncontrolled under commercial-steel specifications, it is necessary, as has been done in programming the research project under consideration, to specify the test steels according to criteria not employed in standard specifications for plate steels. In so doing, a considerable knowledge of such variables upon the properties of steel is implied, and the question might be properly raised, as it was in Committee discussion, as to what there is to be gained through further expenditures to again demonstrate what is already known.

"The objectives of the proposed investigations on influences of variables in steelmaking practice on actual plates, such as are used in fabrications, is to forcibly demonstrate the extent to which certain uncontrolled variables might affect fabrications. Mere test bars do not carry the weight of influence upon engineering thinking as do demonstrations upon simulated structures. Therefore, the value of the proposed investigation would be to demonstrate with unquestionable significance upon sections similar to those entering construction, what can now only be inferred through test-bar investigations. After such investigations have shown with sufficient finality that current steel specifications do not adequately define the materials needed for pressure vessel construction, it is to be hoped that these investigations will carry sufficient weight to secure the introduction into such standard plate steel specifications as A.S.T.M.-A70 (now A 285) the definitions, requirements and tests needed in the procurement of steel deemed suitable for exacting pressure vessel fabrication."

From the outset of its deliberations the Fabrication Division realized that the test program which it planned to conduct could not be expected to reveal much not already known, in a general but not measured way, from experience and previous uncoordinated researches, about the effects of fabrication on carbon steels without knowing fully the reasons therefor; nevertheless, the Division felt that a comprehensive and completely recorded investigation by one group of men, mainly on steels of known histories, would be worth while in

educating the participants and sponsors, emphasizing the inability of present A.S.T.M. specifications to control steel quality; adding weight to the need for and aiding in the development of better procurement specifications; and alternatively and practically showing how, by improved test, design and fabrication practices, to make safe-welded pressure vessels out of the poorly controlled carbon steels currently supplied and which, probably, will continue to be supplied and used for some time to come.

WHAT HAS BEEN DONE

The major test program was assigned to Lehigh University and the published Progress Reports listed below record the work done there.

No. 1. "Comparison of Notch Tests and Brittleness Criteria," by C. J. Osborn, A. F. Scotchbrook, R. D. Stout and B. G. Johnston, THE WELDING JOURNAL **28**, Research Suppl., 24-s to 34-s (1949).

No. 2. "Composition and Property Variation of Two Steels," by C. J. Osborn, A. F. Scotchbrook, R. D. Stout and B. G. Johnston, THE WELDING JOURNAL, **28**, Research Suppl., 227-s to 235-s (1949).

No. 3. "Effect of Plastic Strain and Heat Treatment," by C. J. Osborn, A. F. Scotchbrook, R. D. Stout and B. G. Johnston, THE WELDING JOURNAL, **28**, Research Suppl., 337-s to 353-s (1949).

No. 4. "Effect of Welding on Pressure Vessel Steels," by A. F. Scotchbrook, L. Eriv. R. D. Stout, and B. G. Johnston, ASME Preprint, paper No. 49-A-49, January 1950: Bulletin No. 4, Welding Research Council, February 1950.

A supplementary program of tests on cold-pressed hemispherical heads of small diameter is in progress under the auspices of the Subcommitte on Cold-Formed Heads. To date the heads and their testing have been contributed by the Lukens Steel Co. of Coatesville, Pa., and the Commercial Shearing and Stamping Co. of Youngstown, Ohio. The purpose of this program is to determine the properties of cold-formed heads as they are actually made and used successfully, with the ultimate objective of writing into pressure-vessel codes such minimum requirements as are needed for as-fabricated pressure-vessel materials.

No reports have been published yet but some of the results will enter into the discussions of this Interpretive Report.

MATERIALS TESTED AT LEHIGH UNIVERSITY

For test purposes an aluminum-killed steel ordered to A.S.T.M. Specification A201 and a rimmed steel ordered to A.S.T.M. Specification A70 (now A285) were chosen, and each was supplied in plates $^5/_8$ and $1^1/_4$ in. thick. It was expected that the A201 steel would prove to be much tougher than the A70 steel and, in general, it was so. In Progress Report No. 2 listed above are given the complete mill histories of these materials, together with the variations within the ingots of chemical compositions and physical properties. These variations were found to be normal; they, and some other interesting relations, may be summarized thus:

(*a*) As measured by tension tests the ductility increased and the strength decreased from top to bottom, and from center to edge, of the ingots; as measured by the Charpy keyhole notch impact test the toughness increased and the transition temperature lowered (the steel failed brittlely at a lower temperature) from top to bottom of the ingots; the chemical variations were consistent with these physical variations.

(*b*) The yield points reported by the steel mill were strikingly higher than those measured at Lehigh, in some cases 10,000 psi. higher. These differences may be due to a commercial cross-head speed of 0.500 in. per minute in the mill and only 0.006 in. per minute in the laboratory.

(*c*) Normalized plates had greater ductility and lower Charpy keyhole-notch transition temperatures than as-rolled plates.

(*d*) Transition temperatures determined by double-width Charpy keyhole-notch impact specimens, because of greater lateral restraint, were higher than those determined by specimens of standard width.

(*e*) Plates $^5/_8$ in. thick had a higher yield point, greater strength and lower transition temperature than plates $1^1/_4$ in. thick.

(*f*) The A70 steel had a Charpy keyhole-notch transition temperature about 70° F. higher than that of the A201 steel.

(*g*) Tensile specimens tested transverse to the direction of rolling were somewhat less ductile than those tested parallel thereto.

CHOICE OF TRANSITION-TEMPERATURE TEST SPECIMEN

Since there was no generally accepted test for transition temperature, the Division had to decide which one to use for the Lehigh program. The Charpy impact test was then under suspicion for this purpose because its results on certain ship steels were thought to be inconsistent with those obtained from the wide (up to 72 in.) transversely and centrally notched plate specimens used by the Ship Structures Committee in its investigation of ship failures. (More will be said of this later.) Therefore slowly loaded notched-bend specimens were favored.

The Lehigh Metallurgical Dept. was quite familiar with one such specimen, the so-called Lehigh slow notched-bend specimen, having previously developed and used it for studying the effects of welding on steels. Also well known because they had recently been used and publicized, were the (Navy) tear test and the Penn State (Schnadt) slow notched-bend test. These three tests are fully illustrated and described in Progress

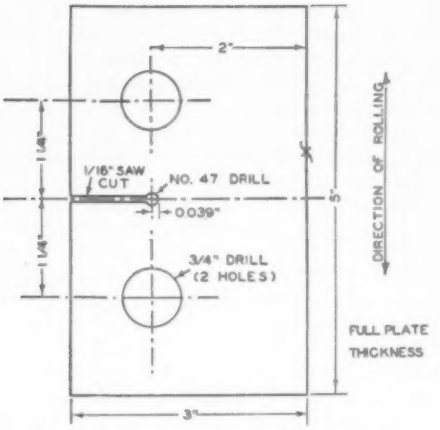


Fig. 1 Specimen used in the Kahn tear test

Report No. 1 listed above. Figures 1, 2 and 3 from that Report are reproduced here; they show that, although the sizes and shapes of the specimens differ, each has a machined notch where failure starts and continues through the metal back of the notch; this sequence of events they have in common. Each has its own loading speed.

The Division decided to make comparative tests using the Lehigh, Navy (Kahn) and Penn State (Schnadt) methods in determining transition temperatures of samples of the A201 aluminum-killed and A70 rimmed steels, in $\frac{5}{8}$ and $1\frac{1}{4}$ in. thicknesses, which were purchased for use in the main program, and for which complete mill histories appear in Progress Report No. 2. These comparative tests proved to be extremely helpful for out of them came not only the adoption of the Lehigh slow notched-bend test but, far more important, a clearer understanding and interpretation of transition-temperature testing than had been known before. With Progress Report No. 1 there should be read the paper "The Meaning and Measurement of Transition Temperature" by R. D. Stout and L. J. McGeady, The Welding Journal, 27, Research Suppl., 299-s to 302-s. Because of their great value the line of thought of the investigators and their conclusions will be discussed at some length.

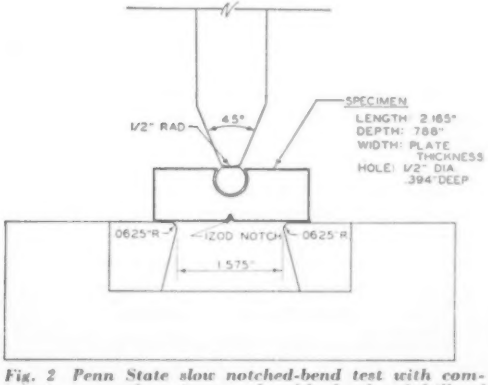


Fig. 2 Penn State slow notched-bend test with compression zone of specimen replaced by hardened drill rod

Various criteria of brittleness of notched specimens have been and can be used; some of them are:

1. Appearance of the fracture.
2. Per cent contraction below the notch.
3. Energy required to break the specimen.
4. Energy absorbed after passing the maximum load.

Transition temperatures determined by different types of tests can logically be compared only when the same criterion of brittleness is used. Failure to observe this simple and seemingly obvious rule has caused much confusion.

Machined notches are used in slow notched-bend specimens to set up, during bending, stress systems conducive to brittle fracture. The sharper the notch the more the restraint, the higher the stress, the harder for plastic deformation to occur, and the greater the probability of brittle fracture in the notch. All of this seems straightforward and correct.

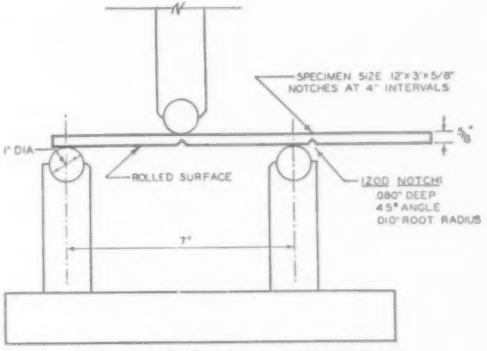


Fig. 3 Lehigh slow notched-bend test

Likewise, the lower the temperature the more likely is the notch to fracture brittlely and the less is the plastic yielding prior to fracture. This also seems reasonable and in accord with common experience.

It is also plain that metal for some distance back of the notch must strain and work harden at the same time that the surface and near surface metal of the notch strains and hardens.

Therefore, when a crack develops in the notch, whether it be of the ductile or brittle type, it constitutes a new and extremely sharp notch, in the work-hardened zone back of the machined notch, so that, as bending continues, this crack progresses and eventually separates the specimen.

Keeping these relations and this sequence of events in mind, it is easy to see that, at some test temperature well above atmospheric, both the notch and the metal back of it will fail ductilely; that, as the test temperature is lowered a temperature will be reached at which

the notch will fail ductilely and the metal back of it brittlely; and finally, that a temperature will be reached low enough so that both the notch itself and the metal back of it will fail brittlely.

Thus the Lehigh slow notched-bend test clearly determines two transition temperatures, the higher one for the strain-hardened material back of the notch, the lower one for the surface and near-surface material of the notch.

The higher transition temperature may be determined with fracture appearance or the energy absorbed after maximum load, as criteria; the lower transition temperature may be determined with bend angle at maximum load, energy absorbed up to maximum load, per cent contraction in width below the notch, and transition from ductile to brittle fracture of a thin zone below the notch, as criteria.

The investigators at Lehigh assigned to the higher transition temperature the designation (T_B), and to the lower one the designation (T_N). (T_N) they called the "ductility transition temperature"; (T_B) they called the "fracture transition temperature." Thus (T_N) may logically be considered as the temperature of transition from ductile to brittle fracture under the stress conditions imposed by the machined notch as modified by plastic straining prior to failure; and (T_B) as a similar transition temperature for the stress conditions existing at the base of a sharp crack formed just below the machined notch.

As previously pointed out, (T_N) is sensitive to the sharpness of the machined notch (it is a measure of notch toughness); it is also sensitive to other surface or near-surface effects to which (T_B) is wholly or practically insensitive. (T_N) has to do with the origin of a crack and (T_B) with its propagation.

Each of the three tests used, the Lehigh, the Navy and the Penn State distinguishes (T_B) and (T_N) the former being from 100 to 200° F. higher than the latter.

(T_B) for the rimmed steel A70 was considerably higher than for the aluminum-killed steel A201 in their as-rolled conditions, the difference being about 60° F. (T_B) generally increased with cold work and strain aging. In all tests (T_B) for $1^1/_4$-in. plates was about 60° F. higher than for the corresponding $^5/_8$-in. plates.

Indications were that the differences in transition temperatures of corresponding $1^1/_4$- and $^5/_8$-in. plates were largely the result of their differing cooling rates after rolling. (The $1^1/_4$-in. specimens were machined on the side opposite the notch, to a thickness of $^5/_8$ in., before testing, thus eliminating thickness as a test factor.)

The Lehigh test was chosen partly because the Lehigh staff was used to it; partly because it had proved useful in studying welding effects on steel; partly because it is simple; partly because it yields duplicable results; partly because it clearly distinguishes (T_N) and (T_B) and partly because it is readily adaptable to cylindrically bent specimens.

In considering Progress Report No. 1 there should be kept in mind the fact that for all three types of specimens, failure had to start at the base of the machined notch and then continue through the rest of the specimen, and that in actual welded structures there seldom are any machined notches but often are either surface or subsurface cracks or other defects.

This suggests the idea that the machined notch of the Lehigh slow notched-bend specimen could be made progressively sharper and sharper until it would be indistinguishable from an actual crack. Would (T_N) then equal (T_B)?

This discussion leads back to the wide centrally and transversely notched-plate specimens previously mentioned in connection with the Charpy impact test. A recent paper, "Evaluating Notch Toughness" by R. W. Vanderbeck and M. Gensamer, THE WELDING JOURNAL, January 1950, Research Suppl., 37-s to 48-s, utilizes the Lehigh work of the Fabrication Division as the basis for the authors' logical contention that (T_N) was not determined for the wide centrally and transversely notched-plate specimens since all of them showed considerable ductility at the ends of the notch, and that behavior at low-energy levels is of major importance in determining ship performance.

They also said *yes* to the question concluding the second preceding paragraph and backed up this answer both by logic and by tests using Charpy V-notch impact specimens, each with a small fatigue crack caused by flexing, at the base of the notch. Furthermore, they demonstrated that, for this type of test, the change from ductile to brittle behavior occurred slowly over a wide range of temperature, and they expressed the opinion that such behavior represents, better than that of the wide centrally and transversely notched specimens, the behavior of a ship. This opinion is supported by the operation of ships at temperatures far below the transition temperatures determined by the wide plate tests, and is consistent with the fact that cracks on many ships grew slowly while the ships continued in service. These observations have parallels in the field of pressure vessels.

EFFECT OF PLASTIC STRAIN AND HEAT TREATMENT

Progress Report No. 3 covers the work done at Lehigh University on the effects of cold work alone, and of cold work followed by heat treatment, on the properties of the aluminum-killed A201 steel, and the rimmed A70 steel, for which Progress Report No. 2 gives the complete mill histories.

The first part of the program consisted of Lehigh slow notched-bend tests, Charpy V-notch tests and standard 0.505-in. tension tests, on material permanently cold strained 0, 1, 5 and 10% in tension in the direction of rolling; 1% in tension transverse to the direction of rolling and 1% in compression in the direction of rolling.

The second part of the program consisted of similarly testing specimens first cold strained as above and then

heat treated at atmospheric temperature, 500, 800, 1150 and 1600° F. for 1 hr. per inch of thickness.

The results may be summarized as follows:

1. Neither the cold straining nor the heat treating to 1150° F. caused any evident change in microstructure, but heat treating at 1600° F. refined the grain size.

2. The tensile strength of neither steel was much affected by cold tensile strains up to 1%.

3. Both the yield strength and, in general, the tensile strength, increased with increasing cold tensile straining. Compressive cold straining lowered the tensile yield strength; this is the Bauschinger effect.

4. Cold tensile straining the A70 steel to 1% greatly increased (T_S), the ductility transition temperature, but further cold tensile straining raised (T_S) only a little more.

On the other hand (T_S) for the A201 steel was consistently raised by increasing cold tensile straining.

5. The two steels had similar strain-aging tendencies.

6. Normalizing at 1600° F. was the only heat treatment which consistently restored the ductility and transition temperature of the cold-worked plates to their as-rolled values. Heat treatment at 1150° F. sometimes partly restored the as-rolled values, but heat treatments at 500 and at 800° F. usually still further reduced the ductility and increased the transition temperature, presumably because of strain aging.

Perhaps in a future program the effects of an 800° F. heat treating temperature held longer than 1 hr. per inch of thickness, will be determined.

7. Cold stretching in one direction raised the yield point in that direction more than at right angles thereto.

Therefore one-direction plastic stretching cannot be relied upon to cause an all-direction increase in yield strength. However, cold stretching in one direction, followed by heat treatment at 1150° F., leaves the material with the same increased yield strength in all directions. Cold stretching decreased the compressive yield point.

NOTE: Directions, as used here, are limited to the plane of the plate.

Caution. Some of the results reported by the Subcommittee on Cold-Formed Heads indicate that a yield point obtained by cold working may, after aging, drop back appreciably toward its original value. Therefore designs based on yield points obtained by cold working should be used only when the permanency of the raised yield points has been established.

Furthermore, designers wishing to take advantage of increased yield points due to cold work should keep in mind that small compressive strains cause a considerable decrease in the tensile yield stress; that, as above indicated, for some steels small tensile strains scarcely affect the yield point; and, finally, that it is hard to strain a pressure vessel uniformly.

8. The $^5/_8$-in. plates had a higher yield point and greater strength than the $1^1/_4$-in. plates but after both were strained 5% in tension parallel to the direction of rolling, the yield points of the two thicknesses were practically equal; however, the strength of the $^5/_8$-in. plate remained slightly higher than that of the $1^1/_4$-in. plate.

9. A 1% compressive strain in the direction of rolling and a 1% tensile strain transverse to the rolling direction had similar effects on the yield point, lowering it when testing was in the rolling direction, and raising it when testing was transversely thereto.

10. When the test direction was the rolling direction there was a sharp knee in the stress-strain curve at the yield point for all degrees of tensile prestraining but when the test direction was perpendicular to the rolling direction the sharp knee disappeared for the large tensile prestrains.

11. A 10% tensile strain in the rolling direction raised the yield point nearly to the nominal (based on the original cross section) maximum strength of the material in the same test.

12. A 10% tensile strain parallel to the direction of test raised the nominal maximum strength about 8000 psi. with specimens tested both parallel and perpendicular to the direction of rolling.

EFFECT OF PLASTIC STRAIN, FOLLOWED BY WELDING AND SUBSEQUENT HEAT TREATMENT, ON THE TRANSITION TEMPERATURE

Progress Report No. 4 covers the work done at Lehigh University to find how different grades of pressure-vessel steels respond to welding and to observe the effects of plate thickness, of plastic strains before welding, of high and low heat-input during welding, and of heat-treatments after welding. The tests were made on six plain carbon steels selected from several mills to cover a range of grades, carbon contents, and deoxidation practices. Two of these steels were the aluminum-killed A201 steel, and the rimmed A70 steel for which Progress Report No. 2 gives the complete mill histories.

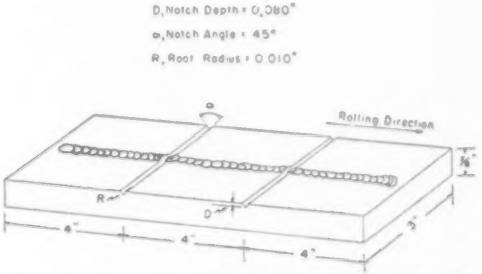


Fig. 4 Lehigh slow notched-bend specimen with weld

Figure 4 illustrates the Lehigh slow notched-bend specimen, with a longitudinal weld, which was used to determine the transition temperature of each steel for each of the following conditions:

(*a*) Welded.
(*b*) Welded and heat treated at 500° F.
(*c*) Welded and heat treated at 1150° F.
(*d*) Stretched 5% cold, and welded.
(*e*) Stretched 5% cold, welded and then heat treated at 500° F.
(*f*) Stretched 5% cold, welded and heat treated at 1150° F.

This schedule was followed for two heat inputs—175 amp. at 10 (in. per minute) and 275 amp. at 8 (in. per minute).

The results may be summarized as follows:

1. Welding appreciably reduced the notch toughness (raised T_N) of the material.

2. The notch toughness of the welded material could not be predicted from the notch toughness of the unwelded material.

3. Welded plates that were strained cold before welding were only a little less notch tough (had slightly higher T_N) than plates that were welded without prior cold straining. Therefore welded joints in cold-formed plates are likely to be nearly as notch tough as welded joints in plates which have not been cold worked. On the other hand (T_B) for strained and welded plates, was appreciably higher than for unstrained and welded plates.

4. Welding reduced the notch toughness (raised the T_N) of $1^1/_4$-in. plates more than it reduced the notch toughness of the corresponding $^5/_8$-in. plates. This seems right since thick plates cool faster than thin plates; thick plates offer greater constraint than thin plates and thick plates have a metallurgical structure less favorable than that of thin plates to notch toughness both before and after welding.

5. The rimmed steels had the highest transition temperatures (both T_N and T_B) after welding, the aluminum-killed steels were next; followed by the semikilled, and the straight silicon-killed steels. The four steels selected at random from mill stock compared favorably with the two steels purchased specially for the Lehigh test program.

6. An 1150° F. heat treatment after welding greatly increased the notch toughness (lowered the T_N) of the plate material affected by the welding. In some cases (T_N) was lowered as much as 70° F. while (T_B) was unchanged.

An 1150° F. heat treatment after both cold straining and welding was even more effective. In some cases (T_N) was lowered as much as 100° F. and (T_B) was consistently lowered too.

7. A 500° F. heat treatment made strained and welded material notch tougher but had no effect on

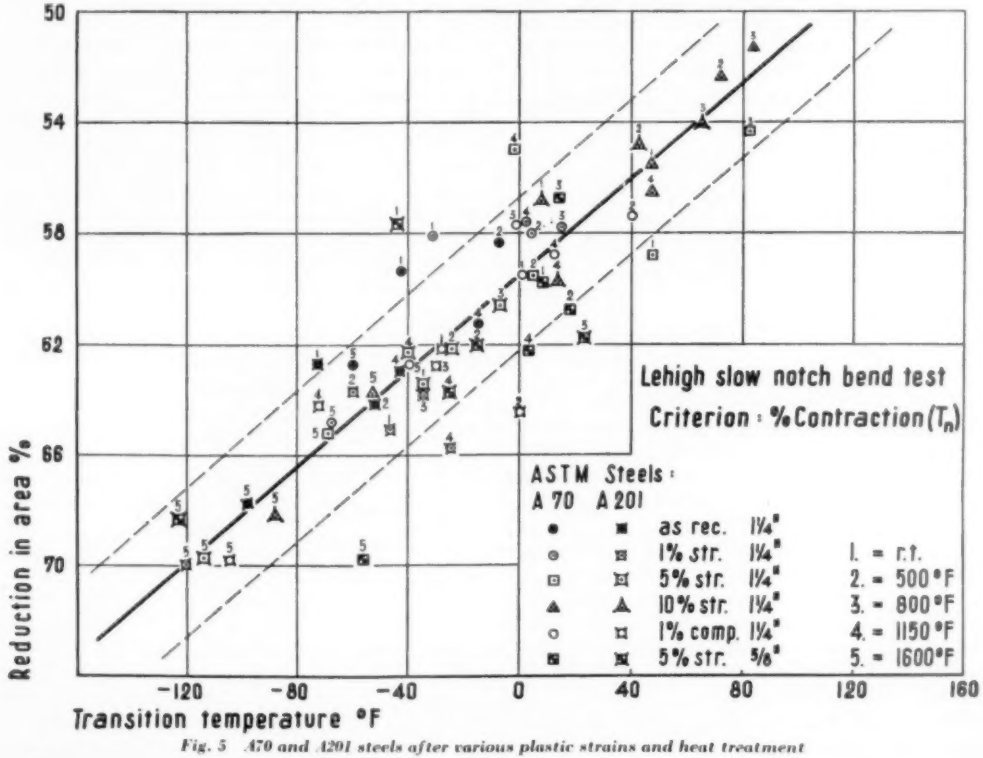


Fig. 5 A70 and A201 steels after various plastic strains and heat treatment

Relation between reduction in area and transition temperature

unstrained welded material.

8. The foregoing results were true for both welding heat inputs. Apparently, for the plain carbon steels tested, the variation in welding heat inputs was too small to make an appreciable difference in test results.

SUPPLEMENTARY INFORMATION

Not reported in Progress Report No. 3 (it will be published in Progress Report No. 5), but constituting an extension thereof, are some very interesting and significant relationships between reduction in cross-sectional area as obtained from tensile tests made at room temperature (using standard 0.505 in. diameter specimens) and (T_N) transition temperatures as determined by the Lehigh slow notched-bend specimens and the (T_N) transition temperatures as determined by the V-notch Charpy specimen. The tensile tests were made on materials that had been treated in the same manner as the materials used for the corresponding transition-temperature determinations. Figures 5 and 6 show that there is a straight-line relationship between the reduction of area and the (T_N) values for the aluminum-killed A201 steel and the rimmed A70 steel, each in $1^1/_4$ and $^5/_8$ in. thicknesses, and in five prestraining, and five prestraining and postheating conditions.

Figure 6 shows (T_N) values from both the Lehigh slow-notched bend test and the Charpy V-notch test plotted against reduction in cross-sectional area in the tensile test. The unavoidable conclusion is that the only difference between Lehigh and Charpy results is that the latter are higher by about 90° F.

However, the most significant fact is that each (T_N) value requires 24 V-notch Charpy tests or 24 Lehigh slow notched-bend tests but only two tensile tests.

Figures 5 and 6 point to the conclusion that reduction in cross-sectional area during the tensile test could, if properly interpreted, be used to determine transition temperatures correlating with those of the now more popular methods; and at a much lower cost.

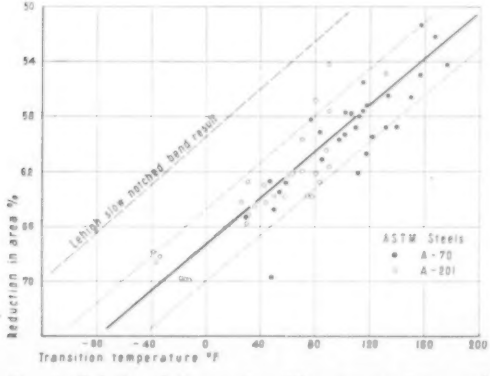


Fig. 6 Relation between transition temperature and reduction in area

V-notch Charpy test criterion: per cent contraction A70 and A201 steels after various plastic strains and heat treatment

It is true that these graphs represent only two steels, but each was subjected to 29 treatments and hence a large variation of properties is represented. Therefore it seems highly probable that the same straight line relationship between tensile reduction in area and Lehigh slow notched-bend transition temperatures (determined by contraction in width below the notch) exists for other materials than the two tested.

Also these results at least partly restore the Charpy V-notch test to its former favored position as a recognized measure of notch toughness in steel.

Nevertheless the Lehigh slow notched-bend specimen has the definite advantage of being extremely versatile. It can be used for cylindrically bent specimens, and for welded specimens; it is easy to prepare and test and the width contractions are large enough to make measuring easy and accuracy high.

SUMMARY

Interpretive Report, Fabrication Division, Pressure Vessel Research Committee

It is easy for designers of welded pressure vessels to go wrong by assuming that steels are unaffected by fabrication, low temperature and restraint; that strains are only elastic and that stress throughout the vessel is uniform and equal to the nominal stress which is the number substituted in the design formula to arrive at the shell thickness. Actually all cold-forming operations raise the yield point closer to the ultimate strength; welding generally reduces the toughness of the heat-affected metal and always locks up a lot of stress in the joints; and even the most ductile material, according to measurements on unnotched laboratory specimens tested at room temperature, fails brittlely under conditions of low temperature or restraint preventing plastic flow. It is a mistake to assume that each cubic inch of metal in the shell of a pressure vessel behaves under service conditions exactly as each cubic inch of metal near the middle cross section of a conventional tensile-test specimen behaves in the laboratory.

Notches, of which cracks are the extreme example, exist in all welded structures due to faulty materials, design or workmanship. The presence of these notches explains why occasional failures occur under moderate loads. A notch may result in a crack which, under some conditions of residual stress in, and general loading of, the vessel, relieves the local high stresses and stops, but which, under other general stress and loading conditions, may aggravate the local stress intensity, wipe out the so-called "factor of safety," and result in a general failure.

Obviously, what is needed to assure safety is one of the following conditions:

1. Materials, design and fabrication so perfect that there are no notches in the vessel either geometrical or metallurgical.

2. Materials so tough that sufficient local plastic straining can occur at each notch, no matter how

sharp, to prevent the formation of a new crack.

3. Neither of the idealized conditions 1 or 2, but a combination of conditions approaching them both such that cracks starting at notches will relieve the local stresses and then stop.

Condition 3 is that of most pressure vessels. No vessel is perfect, and very few vessels fail in a big way, yet cracks are not uncommon during fabrication, under test and less often in service.

The Engineer of today is greatly confused by the term "transition temperature" which was sprung on him not long ago as applicable to pressure vessels. He wonders where the "transition temperature" was in hiding before World War II, and how he got along without it if it is so supremely important today. His bewilderment is increased by the many laboratory tests showing that certain specimens, when loaded in a certain way, change from ductile failure to brittle failure in a short temperature range, and that, although the reported transition ranges for a given material differ widely and often are above the service temperature of the vessel in question, they nevertheless have some significance with reference to that quite illusive thing—the transition temperature or transition temperature range, of the vessel itself.

He wonders what is meant by "the transition temperature of a vessel." He cannot see how a specific little laboratory specimen, with a specific machined notch, and a specific method of loading, can in any way be representative of a whole vessel wherein are many notches both metallurgical and geometrical, each notch with its own special environment, history, residual stress system and potential loading to propagate failure if a new crack should form. He suspects that laboratory transition tests tell a lot about materials but relatively little about entire pressure vessels made of those materials. He looks back over the thousands of welded pressure vessels of the past, many of the earliest of which are still in service, and intuitively puts more faith in them than in the confusing results of, and claims for, the many transition temperature tests of today.

Nevertheless, he is increasingly aware of what is going on in metal research; he is learning its jargon and methods; he is trying to unscramble the mass of befuddling information with which he is plied. He is worried particularly about welded pressure vessels of plain carbon steels operating in the room temperature down to (−20° F.) range wherein the pressure vessel codes require no toughness tests on either the as-rolled or the as-fabricated material yet, for example, permit the use of steel purchased to the A.S.T.M.-A285 Specification under which the mills may furnish rimmed, semikilled or fully killed steel of flange or firebox quality, whatever these terms mean, differing widely in their properties—particularly at low temperatures.

He would like to use better steels but, because of the commercial situation, finds himself unable to do so as long as pressure vessels, made of present materials, continue to satisfy the user and the general public. He wishes that his steel procurement specifications more closely controlled steel quality but recognizes that no major change along this line can be brought about without the active and whole-hearted cooperation of user, steelmaker, fabricator and writer of construction and safety codes. The key man is the user; if ever he becomes sufficiently concerned about things as they are to consistently write into his requests for bids stipulations requiring tougher steels they will be furnished and soon come into general use.

Pending that time, the fabricator will try to make safe pressure vessels with the materials meeting present code rules and enabling him to stay in business on a competitive basis. However, he will keep awake to new knowledge about pressure vessels and be alert to ways of using it effectively.

To the Fabrication Division the Engineer will feel indebted for confirmation of many things which he partly knew before and for some helpful new information.

He has been aware for a long time that cold-forming processes, such as flanging, rolling, pressing and dishing, raise the yield point and reduce ductility. It doesn't surprise him to learn that they also reduce notch toughness as measured by the rise in temperature at which a narrow zone of metal beneath the machined notch of a Lehigh slow notched-bend specimen changes from a ductile to a brittle type of fracture, but he is doubtful about what this means in terms of actual pressure vessels having no machined notches but rather cracks or other defects. He is properly cautious about accepting the idea that there is for a pressure vessel a change from ductile to brittle fracture over a narrow temperature range. His experience is that such general fractures as do occur in pressure vessels are of the generally brittle type whether they take place at room or subroom temperatures.

He is glad to learn that normalizing at 1600° F. is the only heat treatment which surely restores to cold-worked steel its original ductility and toughness, and disappointed to learn that treatment at 1150° F. is not equally effective.

The fact that small cold straining in tension lowers the compressive yield strength and likewise, small cold straining in compression lowers the tensile yield strength is practical information which warns the fabricator not to leave exposed sheared edges which in service will be strained oppositely to the shearing direction, and teaches him to remove such edges by filing or grinding to a rounded contour.

The engineer may find useful the knowledge that cold stretching in one direction raises the yield point in that direction more than at right angles thereto, but that 1150° F. heat treatment after the one-direction straining results in an all-directional uniform increase in yield point. If he wishes to use such an artificial yield point in design he should make sure that aging will not reduce it. The Lehigh tests indicate that the aluminum-killed and rimmed steels tested had similar strain-aging tendencies.

The committee on cold-formed heads has shown that hemispherical heads formed cold mechanically or hydraulically are welded together to form thousands of small spheres which perform satisfactorily in the storage of liquefied petroleum gases in nonshock services—this in spite of the fact that there is very little ductility and toughness left in the material. The Engineer asks himself how much ductility and toughness are needed in a pressure vessel. If he thinks in terms of cast iron and glass, out of which pressure containers are made, he is forced to conclude that very little ductility and toughness are necessary provided the vessel is streamlined and initially free of cracks and other stressraisers. Furthermore, the act of cold forming is itself a severe test of the material and if endured is pretty good assurance that the material is free of faults where cracks might start in service. Considering all of this, the Engineer is loath to set any restrictions, except for low-temperature service, on cold forming other than those automatically imposed by the process and the material. If the fabricator is troubled with cracking he will change either his forming procedure, or his material, or both.

Almost since welding began the Engineer has realized that, as a rule, welding changes the material welded, making it more brittle, and that the higher the carbon content the greater the adverse effect of welding. Of late he is becoming aware that, in general, the loss of notch toughness due to welding could be largely avoided by using less carbon and adding alloying elements to maintain the strength, and that such low-alloy steels have much better low-temperature toughness than plain carbon steels. In spite of this he sees that low-alloy steels cannot displace plain carbon steels, particularly for temperatures down to (−20° F.), without specification, metal cost, and design stress adjustments which will require time and effort.

The Engineer finds in the A.S.T.M. Specifications one designated A-300 under which, for a price, A201 and A212 steels having a minimum Charpy V-notch impact value of 15 ft.-lb. at (−50° F.) can be purchased. The Engineer speculates upon how much of this impact value disappears during fabrication and welding, and upon how much better the completed vessel is than one made of A201 or A212 steel purchased without impact requirements.

For plain carbon steels, heating to 1150° F. and holding 1 hr. per inch of thickness, greatly toughens the welded joints; this is the prescribed A.S.M.E. Boiler Code stress-relieving treatment. Preheating (before welding) to 400° F. has proved to be equally beneficial. Even gas torch heating (after welding) is helpful; its possibilities have not been exhausted, especially, as a means of reducing stress corrosion. Since preheating does not relieve locked-up stresses but nevertheless toughens welded joints as 1150° F. postheating does, it seems plain that the benefits of the latter cannot be due primarily to the relief of residual stresses. The fact is that the reasons for these benefits from preheating and postheating are still obscure.

In view of this discussion it seems unlikely that stress relieving a welded joint merely by stretching it along its length can be beneficial except in rounding out acute stress concentrators. (This statement is not intended to condemn the Linde Method of Low-Temperature Stress Relief which may produce beneficial thermal effects.)

The Engineer is disturbed to hear that the yield points reported by the mill were in some cases 10,000 psi. higher than those determined at Lehigh and would welcome a full explanation of what this means in terms of design based on yield point.

He has reason to expect that welded joints in normalized plain carbon plates will be tougher than those in as-rolled plates. However, this is not always true; in a paper on "Metallurgical Factors in the Embrittlement of Welded Plate" by R. D. Stout and L. J. McGeady, THE WELDING JOURNAL, Research Suppl., 1947, 683-s to 692-s, it is stated:

"On many occasions the effect of previous normalizing on welded plates has been inconsistent from one steel to the next. Apparently the normalizing may improve performance, not affect it, or actually lower it, according to whether the normalizing produces a structure which is more or less sensitive to the intercritical heating than was the as-rolled material."

To the Engineer the most disturbing thing about welded pressure vessels is the uncertainty as to their real factors of safety. The fact that cracks usually stop near where they begin, but sometimes go on to complete failure, indicates that to fail or not to fail can be a touch-and-go affair such that a seemingly insignificant factor, like the snapping of a bolt in a manhole cover, or the temperature of the test water, may decide in favor of "go." It is for this reason, and in spite of the wonderful record of welded pressure vessels to date, that he longs for tougher steels than are now available at prices which he can afford, and hopes for the day when the steelmaker, the code writer, the designer, the fabricator and the user will sit down together and be able to agree upon what procurement specifications should be. He strongly suspects that this hope cannot be realized for a long time because steelmakers themselves do not know why heats intended to be alike are often very different. Quoting from a paper on "Steel Compositions and Specifications," by Charles M. Parker, Secretary, Committee on Manufacturing Problems, American Iron and Steel Institute which appeared in March 1949, as the Number 1 issue of the Welding Research Council Bulletin Series:

"Fundamentally, it is a fact that carbon steels may be produced within the specified chemical limits of a given grade and still have characteristics that are widely dissimilar."

Naturally it occurs to the Engineer that there might be introduced into procurement specifications an arbitrary toughness test such as the Kinzel slow notch-bend test involving both prestraining and welding, but he doubts whether industry as a whole would back it up, particularly for materials used in the room-temperature

down to (−20° F.) range for which the pressure-vessel codes require no impact or other toughness tests of parent plate or welded joint. He knows that on a perfectly logical basis, steels used in this temperature range should be required to meet certain toughness tests, and is worried by the knowledge that he can, under the A.S.M.E. Code rules, provide pressure vessels for operation at (−20° F.) in which the steels at that temperature have nearly zero Charpy V-notch impact values. It is plain to him that the A.S.M.E. Boiler Code Committee could set up a minimum toughness standard for completed vessels for both the parent plates and the welded joints, to cover the room temperature to (−20° F.) range but he is unable to foresee what the ramifications and effects of this action would be and is pretty sure that it will not be taken until the users of pressure vessels sanction and insist upon it.

Therefore, to the Engineer, the work of the Fabrications Division is most helpful in forcing upon him the conviction that, for an unpredictable time, the safety of plain carbon steel vessels will depend more upon careful design, fabrication, inspection and testing than upon improved steel quality. The service record indicates that reasonably safe-welded pressure vessels can be made out of the poorest of the steels presently supplied to the A.S.M.E. and corresponding A.S.T.M. specifications.

From this Report the Engineer sees a possibility that low-alloy steels may be the final answer to the embrittlement problem but that numerous adjustments, involving many interests, must be made before this will be possible.

This Report lends no support to the idea that there can be found a laboratory transition-temperature test correlating directly with pressure vessels—in truth, this Report emphasizes the illusory nature of a transition temperature for a complete vessel. However, the Report encourages an arbitrary toughness test for steels and backs up the concept that even the tensile test at room temperature, if properly modified and interpreted, could be that toughness test. Of the many proposed perhaps the Kinzel slow notch-bend test is the most realistic since it includes, or could be made to include, all of the factors affecting a weldment, including thickness, prestrain and welding.

The thoughtful reader of this Report cannot fail to be impressed by the evident lack of basic understanding about many of the phenomena involved. The Steelmaker does not know, or at least does not control, the factors which produce unlike steels from heats intended to be alike. The Metallurgist does not know why preheating at 400° F. results in welded joints as tough as those postheated at 1150° F., nor does he know why either method does what it does. Of course the precise conditions producing fracture of metals are unknown; probably the initiation of failure goes down into the atomic or subatomic domain beyond the reach of ordinary analysis based on stress and strain. These are a few of the many unknowns in the general field of metals.

This Report should make the Steelmaker even more keenly aware, than he has been, of the needs of the Engineer; it also should make the Engineer appreciate more than he has, the problems of the Steelmaker; and should excite their mutual understanding, sympathy and cooperation.

The Steelmaker will find in this Report evidence that, in spite of his marvelous production record, he is not meeting fully the quality needs of the pressure-vessel industry; this is no news to him. He, better than the Fabricator and Engineer, knows the shortcomings and difficulties of his own business. He is aware of the needs and is trying to meet them. His support of research to that end has been farsighted and liberal; doubtless, he will continue his efforts to improve his products in the face of a growing shortage of high-grade ore.

Editorial Note!

Discussion of this report and additional interpretive conclusions with reference to published reports of the Pressure Vessel Committee and allied fields which can be used by the Engineer in Designing and Fabricating Pressure Vessels is earnestly desired by the Committee. Address Communications to the Pressure Vessel Research Committee, 29 W. 39th Street, New York 18, N. Y.

Effects of Reduced Atmospheric Pressure on Arc-Welding Characteristics

At reduced atmospheric pressures such as found at high altitudes there are some significant changes in arc characteristics which, if understood, can be controlled and utilized to advantage

by M. L. Begeman, B. H. Amstead and U. I. Mashruwala

INTRODUCTION

RESEARCH in the field of arc welding with mild-steel electrodes has revealed the effects of atmospheric conditions surrounding the arc. While special attention has been given to the strength and physical properties of the weld under normal atmospheric conditions, little emphasis has been given to the results of pressure variation in the atmosphere surrounding the arc. This particular investigation was launched to obtain information as to what actually constitutes optimum welding conditions at low atmospheric pressures (simulating high altitudes) and to study the various characteristics of the arc such as burn-off rate, penetration, crater formation and spatter loss.

The procedure followed in this investigation was to weld mild-steel plates in an enclosed chamber at various pressures down to 5-in. Hg absolute with a semiautomatic welding head. Beads were first deposited under conditions which were optimum for the electrode when atmospheric pressure surrounded the arc. Later optimum conditions were determined for the various pressures by running beads at different currents and arc lengths.

Both straight-and reverse-polarity electrodes of the same grade, but made by different manufacturers, were studied under identical conditions. For reverse-polarity welding, E6010 was chosen because of its wide use, and for straight-polarity its counterpart E6013 was selected. All electrodes used were $^5/_{32}$ in. in diameter.

EQUIPMENT USED

The primary apparatus used in this study consisted of a d.-c. motor-generator set, a control panel, a vacuum chamber and a semiautomatic welding mechanism or welding head. Figure 1 indicates the relative position of these components. The motor-generator, not shown in the figure, consisted of a 15 hp., 1750 rpm., 3 phase, 60-cycle induction motor directly coupled to a differentially compound wound d.-c. generator, which at full load delivered 200 amp. at 40 v.

The vacuum chamber, 24 x 24 x 24 in. in size, was designed with bolted port holes on five of its sides for access and observation. Two $^3/_4$-in. inlet air pipes, with stop cocks at the bottom of the chamber, were provided for regulating the pressure. Near the top of the chamber was a $1^1/_4$-in. exhaust pipe with regulating valve which was connected to the dust filter of the vacuum pump. By adjusting this valve and the air inlet valves it was possible to regulate the pressure inside the chamber to within a tenth of an inch of mercury.

The semiautomatic welding head, shown in Fig. 2, was specially designed for the purposes of this investigation. In principle, it was a screw-driven electrode holder which moved in an inclined plane. The horizontal component of this movement formed the bead or the travel component, while the vertical component of the movement determined the burning of the electrode. By controlling the inclination of the plane of motion and the speed of screw, any desired combination of metal deposition and rate of burning was possible within wide limits. When welding with $^5/_{32}$-in. electrodes under optimum conditions, approximately 2 in. of electrode were consumed per inch of bead length; hence these tests were conducted with a setting to give this ratio. The screw was driven by a variable speed motor, mounted outside the chamber and connected to it through a clutch and flexible shaft arrangement.

TEST SPECIMENS

The specimens were $^3/_8$- x $1^1/_2$- x 4-in. hot-rolled mild steel cut from $^3/_8$- x 4-in. flat bars. Each specimen was numbered and accurately weighed on a balance to

M. L. Begeman is Professor of Mechanical Engineering, **B. H. Amstead** is Assistant Professor of Mechanical Engineering and **U. I. Mashruwala** is a graduate student in Mechanical Engineering at the University of Texas, Austin, Tex.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

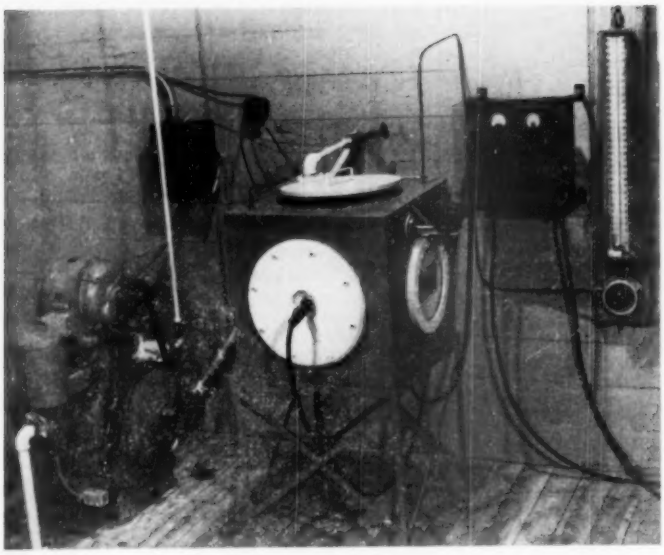


Fig. 1 Photograph of test equipment

one-tenth of a gram.

ELECTRODES

The electrodes used in this investigation are shown below:

Manufacturer	*Trade specification*	*Polarity*	*Classification*
Airco	Airco-78E	Reverse	E6010
Airco	Airco-90	Straight	E6013
Lincoln	Fleetweld 5	Reverse	E6010
Lincoln	Fleetweld 47	Straight	E6013
P. & H.	AP	Reverse	E6010
P. & H.	AC-3	Straight	E6013

All electrodes were dried at 230° F. for 24 hr. in a metallurgical furnace which was in accordance with Winsor's practice of drying electrodes.[1] He observed a marked contrast between the consistency of results with uniformly-dried electrodes and electrodes taken from laboratory stock. Lawrence[2] also mentions that wet coatings are associated with uneven arc performance and puffing of the coating.

TEST PROCEDURE

At the start of a run the testpiece was placed in position and held down with two clamps. The electrode was clamped in the holder, as shown in Fig. 2, and the holder was so adjusted that the electrode was inclined to the vertical about 10° with its tip about $\frac{1}{8}$ in. away from the specimen. A loose ball of steel wool was placed under the electrode forming a contact between the electrode and the specimen; and when the voltage was applied to the electrode, the heavy current fused the wool and started an arc across the small gap.

The electrode speed was then maintained so that the arc length remained essentially constant. As the switchboard was near the observation window, the current and voltage readings on the switchboard panel, appearance of arc, length of arc, spatter characteristics and motor speed were simultaneously observed. Unless all conditions were reasonably steady, the test was rejected.

The actual speed and feed were computed and the length of electrode consumed was obtained by measuring the length of electrode stub. The weight of metal actually deposited was computed as well as the weight of the electrode consumed. Later the physical characteristics of the bead were determined by examining the sectioned specimens.

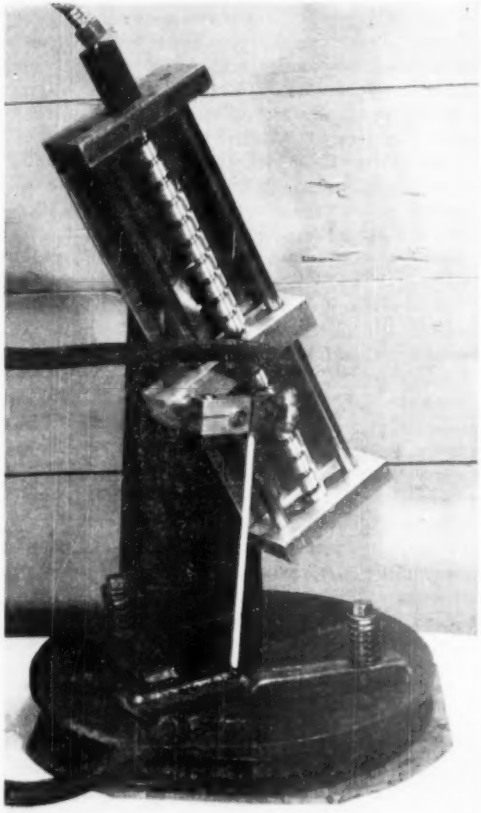


Fig. 2 Photograph of semiautomatic welding head

In order to obtain good contrast, the surface of each transverse section was etched with concentrated nitric acid activated by the presence of hydrochloric acid. It was then washed with dilute hydrochloric acid and finally with water before being dried. The penetration, width of bead, and height of bead were then measured. Photographs of some of the specimens prepared are shown in Figs. 8 and 9. Although they are not clear enough for studying grain structure, the zone of fusion is brought out quite distinctly.

DISCUSSION

The first judgement to be passed on a weld is its appearance, since more can be told by this observation than perhaps by any other characteristic. Of particular significance are the dimensions of the cross section of the head; the bead height, width and penetration. Other variables considered in this investigation are burn-off rate, arc length, energy input and spatter.

Physical Characteristics of the Bead

In this study the physical appearance of welds made at atmospheric pressure was compared with the appearance of those made when the pressure surrounding the arc was reduced. Such dimensions as bead width, height, and penetration were determined at the various pressures and plotted against the energy input to the electrode, as shown in Figs. 3 and 4.

Figures 3 and 4 illustrate that reverse polarity electrodes exhibit greater penetrating properties than straight polarity electrodes. It will be noted that in all cases penetration increases as energy increases; in fact, penetration varies in direct proportion to energy over the range of these tests. This rate of increase remains about constant for all pressures. If the energy supplied to an electrode is held constant and the surrounding pressure is decreased, the penetration is unaffected. Thus penetration is not a function of surrounding pressure but of heat input.

The factors affecting bead width beside energy and pressure are fluidity of molten metal, rate of electrode travel, burn-off rate, spatter, coating thickness and arc length. The two latter factors affect bead width in that they change the distribution of the arc stream over the workpiece. The width of the beads made in these tests increases in direct proportion to the energy supplied. In all tests the reverse polarity electrode gave wider beads. The width of a bead decreased for both types of electrodes as the pressure decreased.

Since in these tests the deposition rate remained constant, it would be expected that bead height would be reduced if bead width were increased. However, results indicate that over the normal welding range, bead height remains constant at any pressure. Reverse-polarity electrodes exhibited a bead height greater than straight-polarity electrodes, and the percentage difference between the two remained almost constant as the pressure was reduced. In every case bead height was reduced when pressure was lowered.

Unfortunately, curves such as those shown in Figs. 3 and 4 do not tell the entire story of the physical appearance of a bead. This is particularly true at decreased pressures when the width and height dimensions of a bead may appear well proportioned, yet the shape of the bead may be far from normal. It is well to remember that in interpreting these figures the curves apply only to a normal welding range that has been slightly extended and that increased penetration does not necessarily imply added electrode material to the base metal.

At this point it is interesting to note that Doan[3] found in examining the appearance of beads that no crater was formed when they were deposited in inert gases. Only in the presence of an admixture of oxygen did he note a crater. In this study it was found that at low pressures where oxygen content was low, the crater was not so prominent at the end of the bead as it was at the end of a bead made at atmospheric pressure.

Burn-off Rate

The quality of a weld is determined to a large extent

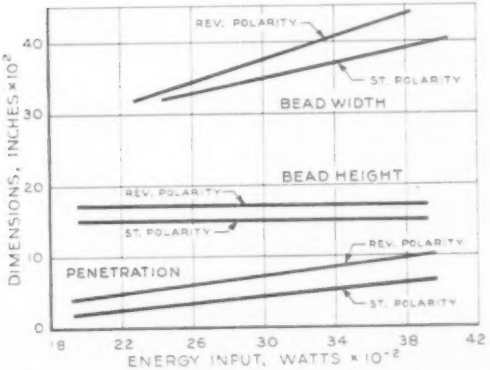


Fig. 3 Effect of energy input on bead dimensions at atmospheric pressure

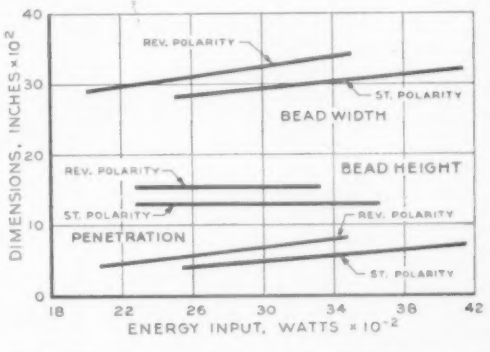


Fig. 4 Effect of energy input on bead dimensions at 5-in. Hg absolute

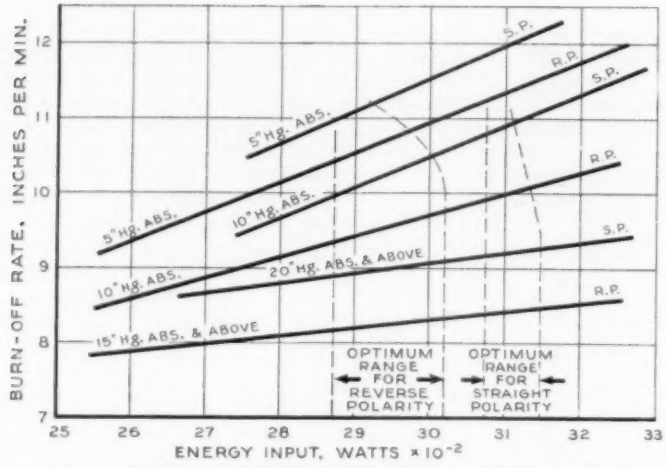


Fig. 5 Burn-off rate as a function of energy input for straight- and reverse-polarity electrodes

by the smoothness of metal transfer from the electrode to the base metal. Approximately 85 to 90% of the electrode metal is transferred in the liquid form, and consequently the character of metal transfer is influenced by the rate at which the electrode is consumed. Martin[4] states that burn-off rate is influenced by many factors, but for a given-size electrode it varies with the current, is dependent upon polarity when direct current is used and is influenced slightly by changes in arc voltage (arc length). Also, the same electrode, used with the same current value, has a higher burn-off rate with straight polarity than with reverse polarity.

The influence of energy input upon burn-off rate for both straight- and reverse-polarity electrodes is shown in Fig. 5. The curve also shows what effect the surrounding pressures have on the rate an electrode is consumed. All curves shown in the figure portray average results; however, data from various electrodes used did not vary from the average more than 5%. The area between the dotted lines in the figure identifies the optimum welding range as obtained from these tests.

Examination of these curves shows clearly that burnoff rate is appreciably increased as the surrounding pressure is decreased. It appears that straight-polarity rods exhibit a greater burn-off rate than reverse-polarity rods, the burn-off rates at optimum welding conditions being, respectively, 12 in. per minute and 10.5 in. per minute at the 5-in. Hg absolute pressure. This may be partially explained by the fact that straight-polarity electrodes require greater heat input than reverse-polarity electrodes when welding under optimum conditions.

As expected, burn-off rates at all pressures increase as the heat input is increased. The rate of increase is slightly greater at the low pressures than under atmospheric conditions, but the trend is fairly uniform for both straight and reverse polarity electrodes.

Figure 6 shows the burn-off characteristics of straight and reverse polarity electrodes at various pressures and at various energy inputs. In the case of reverse-polarity electrodes where the optimum energy input is approximately 2900 watts, it will be observed that for pressures above approximately 15-in. Hg absolute there is little change in burn-off as the pressure increases. For straight-polarity electrodes this critical pressure is at a higher value for the optimum energy input; being approximately 18-in. Hg absolute. This graph indicates then that reverse-polarity electrodes exhibit a more constant characteristic to lower absolute pressures than do straight-polarity electrodes. It will be observed, however, that once the critical pressure is reached, burn-off increases rapidly with further decrease in pressure; reverse-polarity electrodes exhibiting the least stable characteristics.

Martin[4] mentions that burn-off rate is probably dependent on ionization potentials and the disassociation characteristics of the coating. It is quite possible then that the sudden increase in burn-off rate at lower pressures, as observed in this study, is a result of these factors.

Arc Length

It is well established that arc voltage is essentially a linear function of arc length. Winsor[1] found that this was true for the range 24–30 v. at various currents

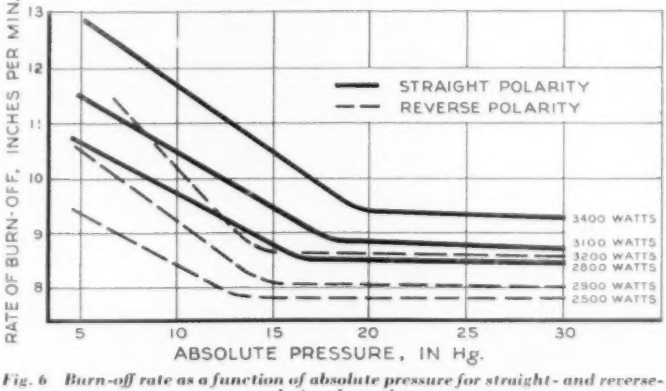


Fig. 6 Burn-off rate as a function of absolute pressure for straight- and reverse-polarity electrodes

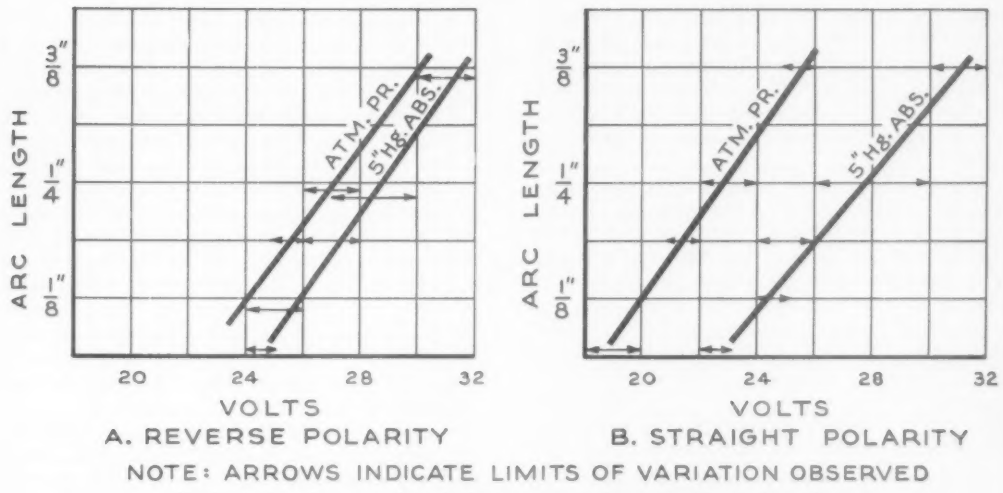


Fig. 7 Arc length vs. arc voltage for both reverse- and straight-polarity electrodes

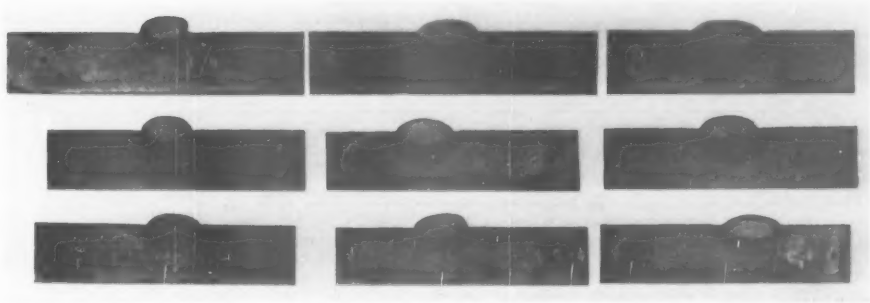


Fig. 8 Macrograph showing the effect of current variation on bead shape using reverse-polarity electrodes—arc length held constant

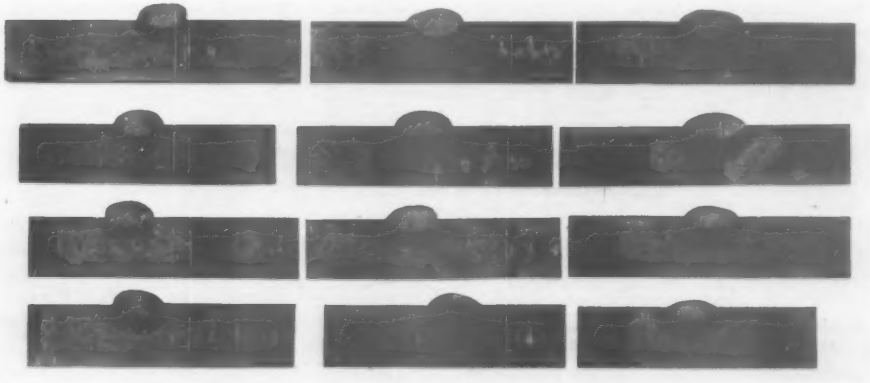


Fig. 9 Macrograph showing the effect of arc length variation on bead shape using reverse-polarity electrodes—arc current held constant

from 120–240 amp. In his experimental studies on Type E6010, $^5/_{32}$-in. diameter electrodes, the voltage varied from 24 to 31 v. at 120 amp. as the arc length varied from 0.125 to 0.250 in. He also substantiated the fact that in the case of a constant arc length, the voltage drop across the arc increases with a decrease in current.

In this study arc length was found to be a linear function of voltage throughout the range of pressures studied, as shown in Fig. 7; that is, as the arc length was increased an increase in voltage was necessary. This figure also shows that welding at low pressures requires a higher voltage for a given arc length than when welding under normal conditions. Spraragen[5] states that gas producing coatings on electrodes changes the voltage drop across the arc and that welding with such electrodes is equivalent to welding in an artificial atmosphere. At lower pressures the atmosphere surrounding the arc must necessarily contain a higher proportion of liberated gases as compared to normal pressure. This difference in composition of atmosphere around the arc may account for part of the greater voltage drop across the arc which is observed at low pressures.

The trend of voltage increase with increase of arc length was similar for both reverse- and straight-polarity electrodes, particularly at low pressures. The range of arc lengths, $^1/_8$ to $^3/_8$ in., was selected as it was only within this range that a bead could be made. It was difficult to maintain an arc closer than about $^1/_8$ in., since the electrode stuck to the base metal by short circuiting. On the other hand, an arc was not stable when it exceeded about $^3/_8$ in. It was interesting to note that for both straight- and reverse-polarity electrodes an ineffective non-welding arc could be maintained at arc lengths greater than 5 in. at 5-in. Hg absolute pressure. Also it was possible to maintain a shorter arc at low pressures with the straight-polarity electrodes since the thicker shielding sleeve prevented sticking of the electrode and directed the arc more efficiently. The resulting bead, however, was not so good as that obtained with reverse polarity when welding with short arc lengths.

In order to establish the optimum welding conditions at various pressures, the arc length was held constant at an approximate optimum value (established by trial and error) and the current varied. Figure 8 shows sectional views of the beads as obtained with reverse-polarity electrodes. In this case it will be noted that a low current deposited "cold" welds with low penetration at all pressures, overlap being present in most cases. High currents deposited flat beads with slight undercuts at all pressures. Although photographs are not shown, the straight-polarity electrode at 5-in. Hg absolute pressure at a high current showed a circular cross section when examined; that is, reasonably deep penetration but a very narrow bead.

Figure 9 indicates the beads obtained for reverse-polarity electrodes when the arc current was held at optimum value (obtained experimentally) and the arc length was varied. Observation of this figure reveals that at atmospheric pressure a short arc deposited a "cold" bead with a slight tendency to overlap. The optimum arc length, which in this case is approximately $^1/_4$ in., deposited a well-shaped oval bead. At 5-in. Hg absolute short arcs caused a "cold" bead and long arcs caused the bead to be flat and at times undercut. Straight-polarity electrodes at the low pressure indicated similar characteristics for low and medium arc lengths, but for a long arc length the shape of the bead was changed considerably. It appeared as if the rod had been laid rather than deposited on the base metal; there was practically no penetration. The small cross section of the bead was caused by the high spatter loss accompanying the high-energy input and the definiteness of the pattern by the thick shielding sleeve of the straight-polarity electrode.

For optimum welds at low pressure, the arc length was shorter than that used for similar welds at atmospheric pressure, the optimum condition being defined as a compromise between bead appearance and spatter loss. Reverse-polarity electrodes yielded better welds from this standpoint; the two primary reasons being the greater penetrating properties of the reverse-polarity electrodes and the thinner coating on the rod. The thinner coating enables the arc stream to cover a greater working area, which in this case means a more normal-shaped bead.

Spatter

During welding, metal from the arc stream penetrates the base metal and forms the bead on the workpiece. Some of the electrode, however, leaves the arc stream and dissipates itself as globules and vapor in the area surrounding the weld. The metal leaving the electrode which does not form a part of the bead constitutes the spatter loss.

There are several theories offered to explain the cause of spatter, but no single one is fully accepted. Smith[6] states that it seems probable that the violent escape of carbon monoxide evolved within the metal melting at the electrode tip causes miniature explosions which project molten metal away from the rod. "It must be expected, then, that the decarburizing reaction will always occur to some extent during actual transfer of the metal, and even after its deposition in the liquid pool at the weld. The escape of carbon monoxide resulting from this reaction within the molten globules explodes them, projecting smaller particles out of the arc stream, and so explaining metal loss by spatter from the arc." However, Smith maintains that most of the metal lost by spatter is projected out of the molten pool rather than from the arc stream. The liquid metal is observed to boil vigorously for normal steel due to the escaping gases.

Keel[7] maintains that when iron is heated by the welding arc from 2900 to 3270° F., it evaporates as iron vapor from the puddle. As the vapor is drawn toward

cooler regions, the iron condenses and small drops of iron fly off at high speed.

The primary factors affecting the phenomena called spatter are surrounding pressure, arc length, electrode coating, energy input and polarity. In this investigation it was found that spatter increased appreciably with increased arc lengths. Figure 10 is a plot of spatter vs. arc length for both straight- and reverse-polarity electrodes at different pressures. Examination of this figure reveals that at all pressures the rate of increase of spatter with increased arc length remained the same. For same arc lengths the spatter increased almost in direct proportion to decreases in the pressure.

Normal increases or decreases in welding current did not appreciably affect the amount of spatter. Often electrode specifications show a maximum current for an electrode and explain that currents greater than this will give excessive spatter. Actually, results of this study indicate that the current which causes excessive spatter generally has a value above the normal welding range which may be determined by proper bead dimensions and general manual control over welding.

D. C. Smith[8] estimated spatter loss for E6010 reverse-polarity electrodes as 13% and for E6013 straight-polarity electrodes, 7%. Some authorities maintain that spatter loss from straight-polarity electrodes is slightly higher than this value.

This investigation revealed, for atmospheric pressures, a spatter loss for reverse-polarity rods of approximately 14% and for straight-polarity rods, a spatter loss of approximately 12%. The variations in atmospheric pressures as well as the separate weighing of the globules sticking to the base metal contribute to the difference between the spatter losses obtained in this study and those obtained by other investigators. In any event it can be assumed that these figures are lower than those that can be expected during commercial welding.

When the energy being supplied to an electrode is increased, the burn-off rate is greater, but the spatter is not necessarily increased. However, increased electrical input adds greater thermal energy to the base metal and consequently lengthens the time for the liquid pool to solidify. The longer the metal stays in the liquid state, the greater the spatter loss. Any theory that neglects spatter loss in the arc stream itself must assume that the losses from the liquid pool increase in direct proportion to arc length, since the results of this investigation indicated total spatter loss increases in this manner. Increased arc length does increase the

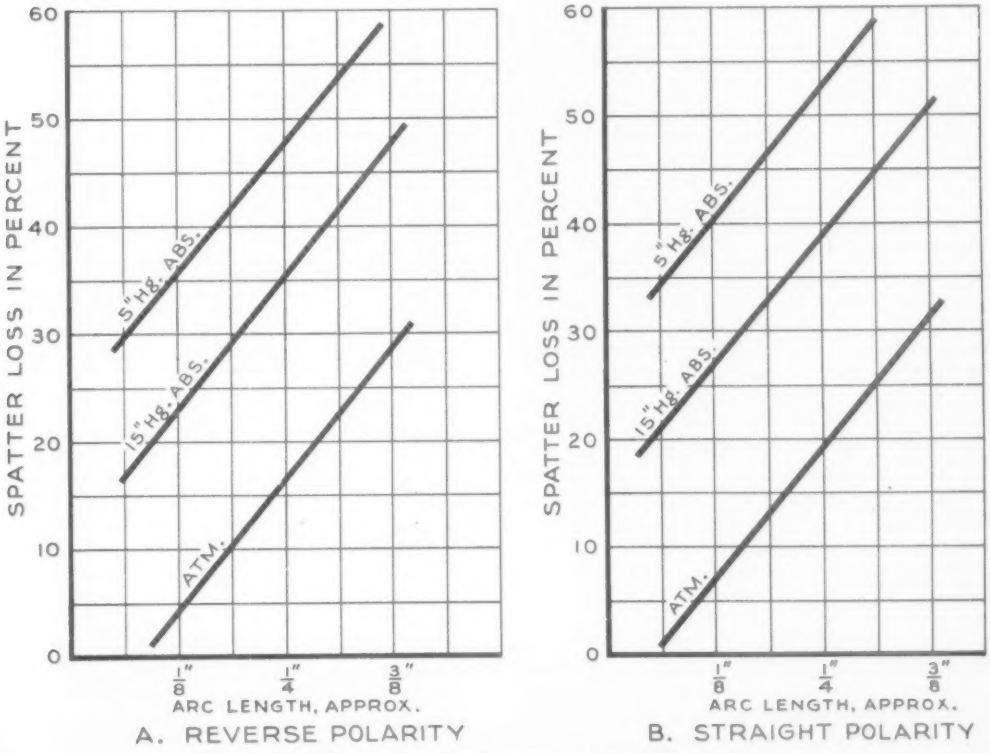


Fig. 10 The influence of arc length on spatter loss at different pressures

splash of metal forced out of the liquid pool as this metal can be seen in the form of globules around the bead. In a few tests these globules were collected and examined. They were found to be very porous shells, so light that their weight accounted for less than 1% of the spatter loss.

At low pressures, the arc stream loses its concentration and, to a certain extent, even its direction is unstable. The magnitude of these effects increases as arc length is increased. Even the straight polarity electrode, with its heavy coating and deep shielding sleeve, exhibited a diverging arc stream which, at the low pressures, spread out like a cone from the electrode tip and covered a relatively large area of the base metal. When this type of arc stream existed, very little spatter was observed as flying globules, and it is reasonable to assume that a large percentage of the loss was due to escaping vapors. Examination of the base metal immediately after a bead was made at reduced pressures indicated the presence of these vapors, since it was always covered with very fine oxidized particles. If the arc length or energy supplied was increased or the pressure reduced, this effect became more prominent. Although all authorities do not agree, some investigators maintain that a substantial amount of the transferred metal traverses the arc stream in the vapor state at atmospheric pressure.

In general, it appears that spatter loss is due to explosions of carburized particles in the arc stream and metal pool, and is also due to the escape of iron vapor from the arc stream and metal pool. At reduced pressures this loss is magnified because of the increased losses due to vapor escaping from the arc stream and liquid pool and the increased intensity of explosions of carburized particles.

CONCLUSIONS

On the basis of the results of this investigation, the following conclusions are noted:

1. If the voltage and current of an electrode remain constant and the pressure surrounding the arc stream is decreased, the bead width and height decrease, but the penetration remains constant. At atmospheric and lesser pressures the bead width and penetration increase with increases in the energy supplied to the electrode, but bead height remains unchanged.

2. Crater formation is not so prominent at the end of an arc made at reduced absolute pressures as it is at atmospheric pressure.

3. As the pressure surrounding the arc is decreased, the arc length for an optimum weld is reduced. Much longer arc lengths can be obtained at lower pressures, but only at the sacrifice of the concentration and direction of the arc stream and at the expense of increased spatter loss.

4. If the energy supplied to an electrode remains constant and the pressure surrounding the arc is decreased, the burn-off rate increases appreciably. At pressures below approximately 15-in. Hg absolute, the burn-off rate increases rapidly as the pressure is further reduced.

5. Reverse-polarity electrodes, although more difficult to weld at low pressures, offer a better compromise between bead appearance and spatter. The straight-polarity electrodes, on the other hand exhibit greater stability and are easier to operate with at low pressure.

6. Spatter loss is proportional to arc length and pressure. This loss is probably due to explosions of carburized particles in the arc stream and metal pool, and also due to the escape of iron vapor from the arc stream and metal pool. The spatter loss varies for an optimum weld from approximately 13% at atmospheric pressure to about 40% at 5-in. Hg absolute.

Bibliography

1. Winsor, L. P., "New Observations of the Welding Arc," presented at Am. Inst. Elec. Engr. Conference on Electric Welding, Detroit, Mich., Dec. 6–8, 1948.
2. Lawrence, Harold, "Metallic Arc-Welding Electrodes," THE WELDING JOURNAL, **23** (7), 610–621 (1944).
3. Doan, G. E., and Lorentz, Jr., R. E., "Crater Formation and the Force of the Electric Welding Arc in Various Atmospheres," *Ibid.*, Research Suppl., Vol. VI, (2), 103-s to 108-s (1941).
4. Martin, D. C., Rieppel, P. J., and Voldrich, C. B., "Burn-Off Characteristics of Steel Welding Electrodes," *Welding Research Council Bull. Series*, No. 3, 1–8 (May 1949).
5. Spraragen, W., and Lengyel, Bela A., "Physics of the Arc and the Transfer of Metal in Arc Welding," THE WELDING JOURNAL, **22** (1), Research Suppl., 1-s to 42-s (1943).
6. Smith, Morton C., "Gas Evolution in Arc Welding Steels and Its Effects Upon the Welding Process," *Ibid.*, **24** (4), Research Suppl., 226-s to 229-s (1945).
7. Keel, C. F., "Spatter in Gas and Arc Welding," *Ibid.*, **22** (12), Research Suppl., 612-s (1943).
8. Smith, D. C., and Rinehart, W. G., "Application and Development of Modern Heavy-Coated Arc-Welding Electrodes," *Ibid.*, **24** (6), 541–548 (1945).

The Projection Welding of 0.010 and 0.020-In. Steel Sheet

In this investigation best results were obtained with annular type of projection, the use of a spring-loaded electrode, electrode conductivities of 28–30% I.A.C.S. and clean surfaces

by E. F. Nippes, J. M. Gerken and J. G. Maciora

SUMMARY

THE effects of projection size and shape, welding current, electrode force, electrode tip material and sheet surface resistance on projection weld quality were studied. An annular ring-type projection gave the best resistance to cold collapse and produced welds having greater symmetry and more consistent strengths than spherical or conical type projections. A spring loaded electrode was found necessary to provide an electrode follow-up rapid enough to prevent expulsion during welding. Low conductivity electrode tips were used to restrict welding currents to reasonable values by reducing heat losses from the weld. Copper-tungsten type tip material, (R.W.M.A. Group B, Class 11 or 12) with conductivities of 28–30% I.A.C.S. gave good results. To obtain clean, consistent welds with a minimum of expulsion and electrode sticking, the sheet surfaces must be clean before welding.

INTRODUCTION

The investigation of projection welding as covered in this report is a continuation of previous work done at Rensselaer Polytechnic Institute. This program, approved and guided by the Resistance Welding Committee, was financially supported by the Welding Research Council for the purpose of broadening the knowledge of projection welding and establishing optimum welding conditions for various types and gages of steel. This report gives the results of the work done on A.I.S.I.-1010 steel in the 0.010 and 0.020 in. thicknesses, and a summary of the recommended welding conditions for A.I.S.I.-1010, 1015 and 1020 steel in the 0.040, 0.062 and 0.125 in. thicknesses.

E. F. Nippes, J. M. Gerken and **J. G. Maciora** are connected with the Welding Laboratory, Rensselaer Polytechnic Institute, Troy, N. Y.

Scheduled for presentation at the Thirty-First Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

EQUIPMENT

A 200-kva. Thompson-Gibb air-operated, press-type welder with provisions for $1^1/_4$-in. diameter electrodes was used for this investigation. A needle valve was installed in the air line to the ram-lowering cylinder to reduce the speed of the ram and thereby reduce the impact force on the projection. A spring-loaded electrode was used to provide the low welding pressures required and still give a sufficiently rapid follow-up. However, this may not be necessary if the moving head of the welder has a low enough inertia to permit the rapid follow-up. An electronic weld timer and phase control was used to regulate the weld time and current. Weld current was measured with a pointer-stop ammeter. Weld time was checked with a Brush direct-inking oscillograph.

MATERIAL AND PREPARATION

The material used for this investigation was A.I.S.I.-1010 steel in the 0.010 and 0.020 in. thicknesses. Chemical analyses of these steels are given in Table 1; the mechanical properties are given in Table 2. This material was received as pickled and oiled from the mill and was then degreased to remove the oil. Unfortunately, the degreased sheet was exposed to indoor air for about 6 mo. and became coated with a thin, high-resistance, oxide film which caused inconsistent weld strengths. To remove this film, all specimens used were pickled in a solution of 50% hydrochloric acid (muriatic) and 50% water for 10 sec., water rinsed, dipped in acetone, and then wiped dry with a clean cloth.

Surface resistance measurements were made on single thicknesses of sheets using a double Kelvin bridge. It was found that the as-received resistance varied from 100 to 2000 or 3000 microhms depending upon the amount of air exposure the piece had. Sanding the surface with 100 grit emery paper reduced the surface resistance to an average of 30 microhms and the pickling treatment mentioned above produced a surface resistance of 8 to 10 microhms. After exposure to air for

Table 1—Chemical Analysis

Item No.	A.I.S.I. No.	Thickness, in.	C, %	Mn, %	P, %	S, %	Si, %	Cu, %	Ni, %	Cr, %
1	1010	0.010	0.11	0.35	0.029	0.024	Trace			
2	1010	0.020	0.08	0.36	0.021	0.019	Trace			
3	1010	0.040	0.08	0.36	0.007	0.028	0.012	0.04	0.06	0.05
4	1010	0.062	0.08	0.36	0.007	0.028	0.012	0.04	0.06	0.05
5	1010	0.125	0.08	0.39	0.010	0.027	0.010	0.06	0.05	0.03
6	1015	0.040	0.15	0.40	0.012	0.012	0.027	0.03		
7	1015	0.062	0.14	0.54	0.014	0.035	0.010	0.011	0.011	
8	1015	0.125	0.14	0.54	0.014	0.035	0.010	0.011	0.011	
9	1020	0.040	0.20	0.45	0.012	0.042	0.003	0.01		
10	1020	0.062	0.20	0.45	0.012	0.042	0.003	0.01		
11	1020	0.125	0.20	0.45	0.012	0.042	0.003	0.01		

3 days the pickled sheets had a surface resistance of about 35 microhms. Pickled sheets, welded after 3 days air exposure, showed no perceptible difference in strength from sheets welded within an hour after pickling.

TESTING PROCEDURE

The methods and specimens used for testing projection welds were described in detail in a previous report.[1] The shear and normal tension tests were used in this work to determine the effects of the welding variables on weld strength. Representative welds were radiographed to determine the extent of porosity and projection extrusion and then sectioned to examine the microstructure of the weld.

For the shear test, two 6- by 2-in. sheets were overlapped 2 in. and the projection or group of projections centered in the overlap. For the normal tension test, two 6- by 2-in. specimens were overlapped at right angles to each other at their centers with the projection or group of projections centered in the overlap. Tension was applied to this specimen by means of a jig designed to minimize sheet distortion and slippage.

Projection cold collapse studies were made on the 0.010-in. sheet at 50, 75, 100, 125 and 150 lb. electrode force and on the 0.020-in. sheet at 100, 125, 150, 175, 200, 225 and 250 lb. electrode force. Three projections of each type tried were coined in the sheet and the height measured with a micrometer. Each of these projections was then subjected to the same electrode force and the height again measured with a micrometer. This procedure was followed at all the electrode forces given above for the two thicknesses of material.

PUNCHES AND DIES

On the 0.020-in. sheet and particularly on the 0.010-in. sheet it was necessary to design a projection having more resistance to cold collapse than the spherical type projections used on thicker sheets. Annular, conical and truncated cone projections were investigated in addition to the spherical type. Of these, the annular was found to give the best combination of resistance to cold collapse and expulsion. The volume of each punch was computed to have the same volume as its mating die. Punches and dies were machined from an air-hardening steel and were hardened and tempered to obtain a hardness of about 53 Rockwell C.

ELECTRODE TIP MATERIAL

In a previous investigation at this laboratory[2] it was found that a low conductivity electrode tip material produced a greater I^2R heat in the electrode tips. This produced a higher tip temperature which meant a smaller heat loss from the weld to the electrodes and a smaller current to produce a given size weld. Since the heat loss to the electrodes is more pronounced when welding thin sheets, where the ratio of contact area between electrode and sheet to weld volume is high, only the low conductivity type electrode tips were used for this investigation on thin sheets.

Copper-tungsten (R.W.M.A. Group B, class 11 or

Table 2—Mechanical Properties

Item No.	A.I.S.I. No.	Thickness, in.	Yield strength, psi.	Ultimate strength, psi.	Hardness, Rockwell B	Elongation % in 2 in.
1	1010	0.010	...	45,180	55*	31
2	1010	0.020	...	43,900	63*	31
3	1010	0.040	...	45,350	50	32
4	1010	0.062	39,100	49,500	52	32
5	1010	0.125	40,700	43,600	52	30
6	1015	0.040	...	50,850	54	25
7	1015	0.062	40,300	53,200	59	32
8	1015	0.125	46,000	55,800	60	31
9	1020	0.040	...	51,030	52	27
10	1020	0.062	49,400	61,450	70	23
11	1020	0.125	46,650	60,200	70	27

* Converted from VPN using conversion chart from 1939 *A.S.M. Handbook*, p. 127.

12) with a conductivity of 28–30% I.A.C.S. and silver-tungsten with a conductivity of 40–45% I.A.C.S. were tried as electrode tip materials. Of these the copper-tungsten type tip material was found to give better results, requiring less current to produce a given sized weld and to produce more consistent welds with less sticking to the electrodes than the silver-tungsten type tip material.

ELECTRODE FOLLOW UP

In welding 0.010 and 0.020-in. sheet, projection collapse is almost complete after the first cycle of weld current. This means that the electrode must have rapid enough follow-up to maintain pressure on the weld as the projection collapses. The force necessary to accelerate the moving head or arm of the welder this rapidly would usually be sufficient to collapse the projection cold before welding starts. For this reason it is necessary to use a spring-loaded electrode for applying the welding pressure. For this type electrode the welder head remains stationary during the weld cycle and only about a 4-in. length of $1^1/_4$-in. diameter copper must move to follow the projection collapse and the welding force supplied by the spring is great enough to produce the acceleration to maintain the force.

WELDING OF THE 0.020-IN. THICK MATERIAL

In studying the projection welding of 0.020-in. thick sheet only the A.I.S.I.-1010 steel was used. It was considered unnecessary by the Subcommittee to repeat welds on the A.I.S.I.-1015 and 1020 steels because the welding conditions and projection dimensions would be expected to be the same for these higher carbon steels although the resulting mechanical properties would be different.

In the design of projections for welding thin sheets, certain conditions must be fulfilled:

1. The projection must have sufficient stiffness to resist excessive cold collapse at the welding pressures. This is necessary to prevent the sheets from coming in contact at points other than the projection and cause shorting.

2. The steepness of the sides of the projection and the ratio of the height to the diameter must both be low enough so that the displaced metal will fall back into its original position on welding rather than be extruded or expelled.

Cold collapse tests were made with three spherical projections: 0.065 in. diameter, 0.007 in. height; 0.085 in. diameter, 0.016 in. height; 0.075 in. diameter, 0.020 in. height. The results of these tests, Fig. 1, showed that at 100 lb. electrode force all projections collapsed about 10%, and at 150 lb. electrode force the 0.075-in. diameter, 0.020-in. height projection collapsed about 30% while the other two collapsed about 75%.

Series of welds were made on these three spherical projections at 100 lb. electrode force, and strength-current curves were plotted. The strengths were erratic, particularly the normal tension strength, and expulsion and electrode sticking were excessive at relatively low current values causing porosity in the resulting welds.

A strength-current curve was determined for the 0.075-in. diameter, 0.020-in. height projection at 150 lb. electrode force, as shown in Fig. 2. More consistent strengths were obtained and the curve was smoother than at the lower electrode force; however, expulsion and electrode sticking were still noticeable at weld currents giving less than a reasonable weld strength.

It was decided to use a higher electrode force and to design a projection of larger diameter and somewhat smaller height to be able to withstand this greater force. An annular projection 0.110 in. diameter and 0.015 in. height was designed as shown in Fig. 3. Cold collapse studies for this projection, Fig. 1, showed that at 225 lb. electrode force the collapse was about 30%. The diameter of the projection was selected as 0.110 in., which approaches the diameter of weld plugs obtained in previous tests with spherical projections.

Welds were made using this annular projection at 225 lb. electrode force, 6 cycles weld time and currents ranging from 2500 to 6000 amp. The current range was determined by the value which just produced a weld to that value which caused expulsion. Strength current curves for the 0.110-in. diameter, 0.015-in.

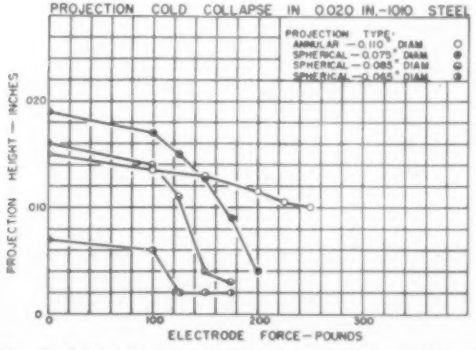


Fig. 1 Cold collapse of projections in 0.020-in. 1010 steel

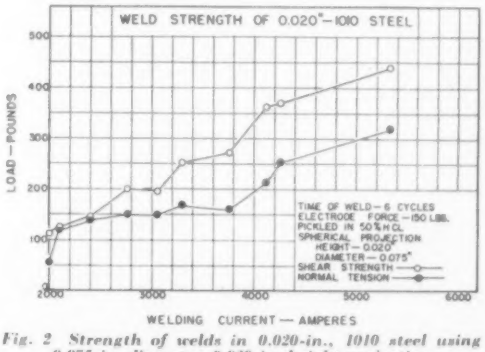


Fig. 2 Strength of welds in 0.020-in., 1010 steel using 0.075-in. diameter, 0.020-in. height projection

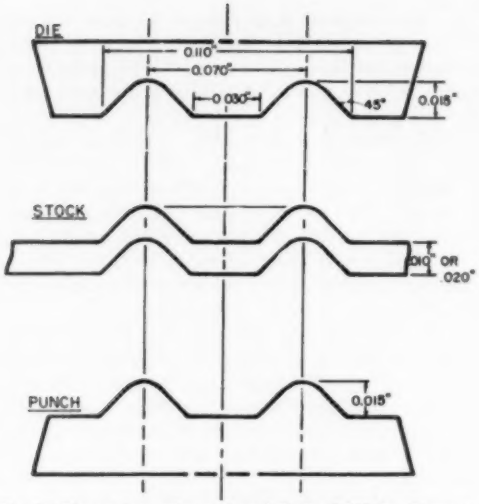


Fig. 3 Dimensions of punch and die for 0.110-in. diameter annular projection

height annular projection are shown in Fig. 4. Comparison of Fig. 4 with Fig. 2 shows that the annular projection permitted use of higher welding currents resulting in greater strength over a greater range of current than the spherical projection. As Fig. 5 shows, the normal tension to shear ratio for the both projections has an almost constant value of 70% in the welding range.

The diameters of the plugs pulled from the normal tension specimens were measured for both the spherical and annular projections and are plotted as a function of welding current in Fig. 6. It was noted that when the weld strength is plotted against the plug diameter the average value is a straight line intersecting both axes at zero. This is to be expected because for a plug-type failure the resisting area is cylindrical and varies directly as the diameter of the plug.

From the strength current curves using the annular projection at 225 lb. electrode force and 6 cycles weld time, a weld current of 5200 to 5600 amp. was considered

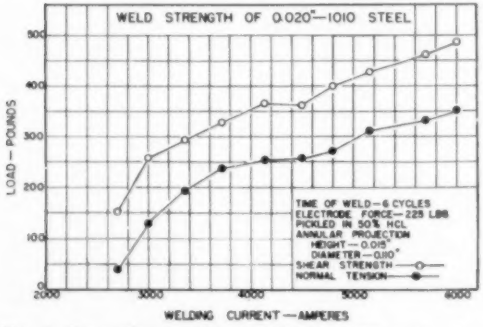


Fig. 4 Strength of welds in 0.020-in., 1010 steel using 0.110-in. diameter, 0.015-in. height annular projection

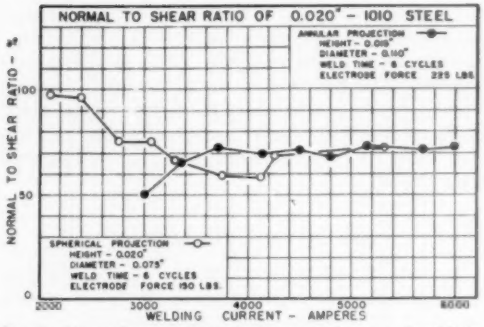

NORMAL TO SHEAR RATIO OF 0.020" — 1010 STEEL
NORMAL TO SHEAR RATIO — %
WELDING CURRENT — AMPERES
ANNULAR PROJECTION
HEIGHT — 0.015"
DIAMETER — 0.110"
WELD TIME — 6 CYCLES
ELECTRODE FORCE 225 LBS.
SPHERICAL PROJECTION
HEIGHT — 0.020"
DIAMETER — 0.075"
WELD TIME — 6 CYCLES
ELECTRODE FORCE 150 LBS.

Fig. 5 Normal strength to shear strength ratio of welds in 0.020-in., 1010 steel

optimum. Using these conditions with 5200 amp. per weld and 225 lb. electrode force per weld, multiple welds were made simultaneously. To determine the best weld spacing, double welds were made at spacings of 0.2, 0.3, 0.5 and 0.7 in. and both shear and normal tension tests made. On the shear tests, welds were spaced in both the axial and transverse direction. The results in Table 3 show that the double weld strength increases up to 0.5-in. spacing and decreases at 0.7-in. weld spacing. Using the spacing of 0.5 in., five specimens each of three and four weld groups were made for shear and normal tension tests. The welds in the three-weld specimens were located at the vertices of a 0.5-in. equilateral triangle having a base perpendicular to the long dimension of the specimen. The welds in the four weld specimens were located at the corners of a 0.5-in. square having an edge parallel to the long dimension of the specimen.

Table 3—Effect of Weld Spacing on Weld Strength of Double Welds, 0.020-In. Thick A.I.S.I.-1010 Steel

Weld spacing, in.	*Shear strength, lb.*		*Normal strength, lb.*
	Axial	*Transverse*	
0.2	618	672	273
0.3	710	760	299
0.5	801	866	383
0.7	841	778	355

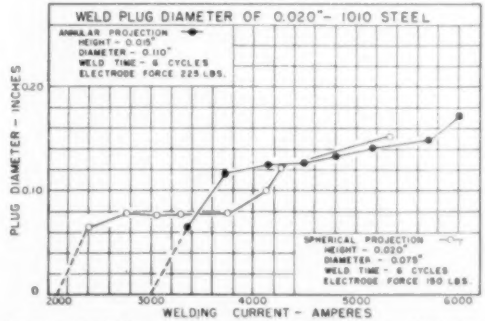


Fig. 6 Weld plug diameter of welds in 0.020-in., 1010 steel

Cross sections of welds in 0.020-in. thick sheet. Weld time, 6 cycles

Annular projection, diameter 0.110 in., height 0.015 in., electrode force 225 lb.

Spherical projection, diameter 0.075 in., height 0.020 in., electrode force 150 lb.

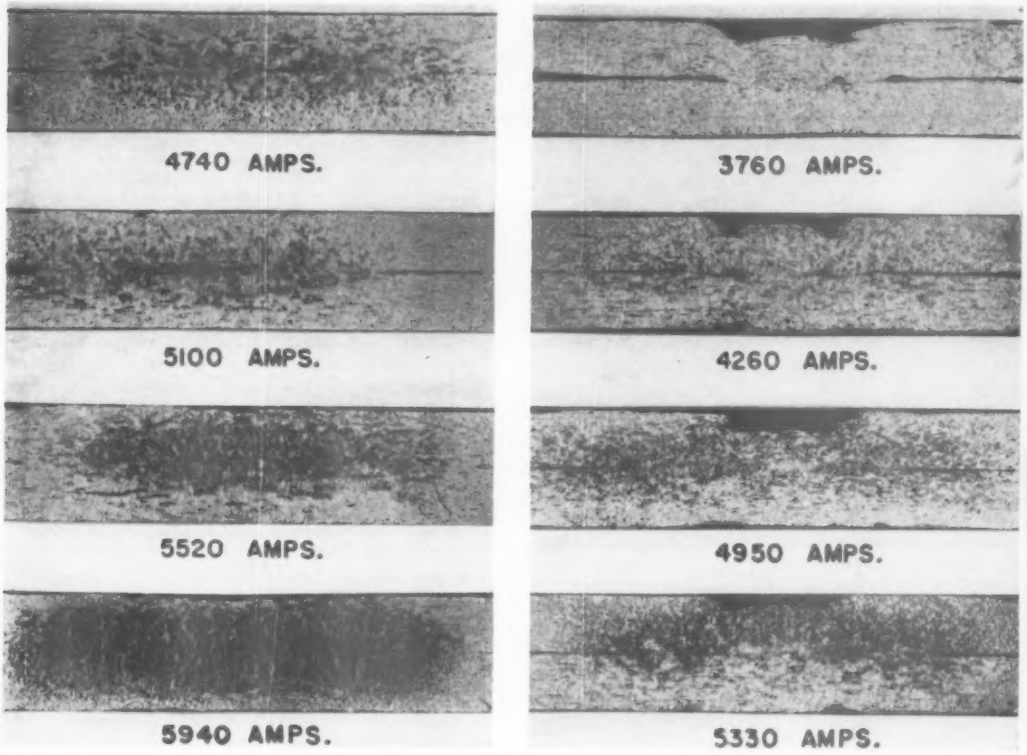


Fig. 7 Macrosections of welds in 0.020-in., 1010 steel for 0.110-in. diameter, 0.015-in. height, annular, and 0.075-in. diameter, 0.020-in. height spherical projections. × 20

The results, given in Table 4 and plotted in Fig. 8, show that as the number of welds is increased the strength per weld decreases. The dotted straight lines represent the hypothetical strength of multiple welds if the strength per weld remained constant.

Table 4—Multiple Weld Strength, 0.020-In. Thick A.I.S.I.-1010 Steel, 0.5-In. Weld Spacing

Number of welds	*Shear strength, lb.*		*Normal strength, lb.*	
	Total	*Per weld*	*Total*	*Per weld*
1	431	431	313	313
2	801	400	383	191
3	984	328	433	144
4	1146	286	574	143

It will be noted that the strength per weld decreases more rapidly for normal tension than for shear. Furthermore, only a small increase in the total normal tension strength is obtained by increasing the number of welds.

Figure 7 shows cross sections of welds made in 0.020-in. sheet with various welding currents. The welds on the left in this figure were made with an annular projection and those on the right, with a spherical projection. These sections show that for the annular projection there is no expulsion or extrusion of projection metal and that the projection indentation is completely collapsed back into its original position. For the spherical projection some of the projection metal has been extruded radially outward resulting in incomplete filling of the punch indentation.

The recommended conditions for welding 0.020-in. thick A.I.S.I.-1010 steel are given in Table 5.

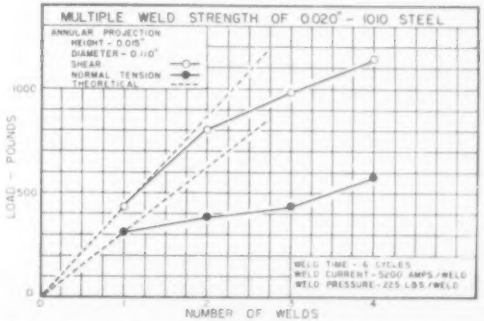


Fig. 8 Strengths of multiple welds in 0.020-in., 1010 steel, using 0.110-in. diameter, 0.015-in. height annular projections

Table 5—Recommended Conditions for Welding A.I.S.I.-1010, -1015 and -1020 Steels in Thicknesses from 0.010 to 0.125 In.

Sheet thickness, in.	0.010*	0.020*	0.040	0.062	0.125
Electrode force, lb.	110	225	450	750	2000
Weld time, cycles	6	6	15	20	45
Welding current range, amp.	5000–5400	5200–5600	5700–6300	8400–8900	14,400–15,000
Projection diameter, in.	0.110†	0.110†	0.140	0.170	0.300
Projection height, in.	0.015†	0.015†	0.025	0.042	0.055
Approximate diameter of fused zone, in.	0.090‡	0.110	0.170	0.190	0.340

* Tests for these thicknesses made only on A.I.S.I.-1010.
† Annular projection as shown in Fig. 3.
‡ Not a completely fused nugget.

WELDING OF THE 0.010-IN. THICK MATERIAL

Welding tests for the 0.010-in. thick steel were conducted only on the A.I.S.I.-1010 steel. The problem of projection cold collapse was more critical in the 0.010-in. thick sheet than in the 0.020-in. sheet, therefore, more shapes and sizes of projections were investigated.

The scheme was to coin a series of each projection, run cold collapse tests on each series, then run welding, tests on the projections which had sufficient resistance to cold collapse. The following projections were investigated.

Diameter, in.	*Height, in.*	*Type*
0.077	0.015	Annular
0.110	0.015	Annular
0.075	0.020	Spherical
0.080	0.025	Truncated cone, 30° sides
0.090	0.030	Conical, 56° sides

The results of the study of projection height after cold collapse are shown in Fig. 9. The spherical and 56° conical projections collapsed excessively at 75 lb. electrode force and were considered unsatisfactory. However, weld tests were made on the spherical projection to compare the results with those for the other types. Weld series were made at 75 lb. electrode force on the spherical projection, at 110 lb. on the 0.077-in. diameter annular projection, at 110 lb. and 130 lb. on the 0.110-in. diameter annular projection, and at 150 lb. on the truncated cone projection.

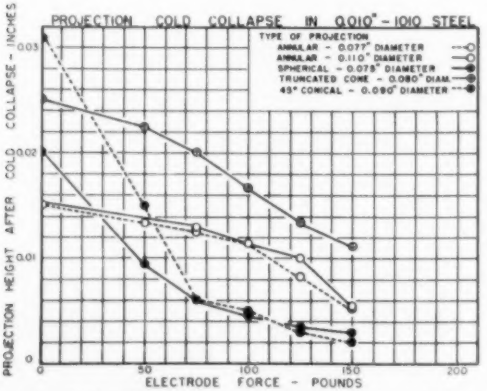


Fig. 9 Cold collapse of projections in 0.010-in., 1010 steel

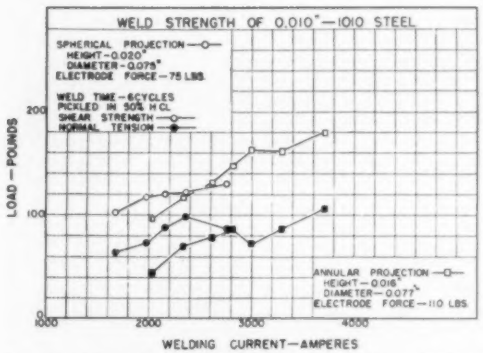


Fig. 10 Strength of welds in 0.010-in., 1010 steel, using 0.075-in. diameter, 0.020-in. height spherical projection or using 0.077-in. diameter, 0.016-in. height annular projection

Strength-current curves for the spherical projection and 0.077-in. diameter annular projection are shown in Fig. 10. Both of these projections expelled at relatively low current values and had correspondingly low strengths. However, the small annular projection was an improvement over the spherical projection.

Figure 11 shows the strength-current curves for the 0.110-in. diameter annular projection welded at 110 and 130 lb. electrode force. Use of the higher electrode force did not increase the shear strength and lowered the normal strength of welds. The higher electrode force also reduced the current range over which the variation in strength was small.

The results for welds made with the truncated cone projection are shown in Fig. 12. The peak values of strength were about the same as those obtained for the

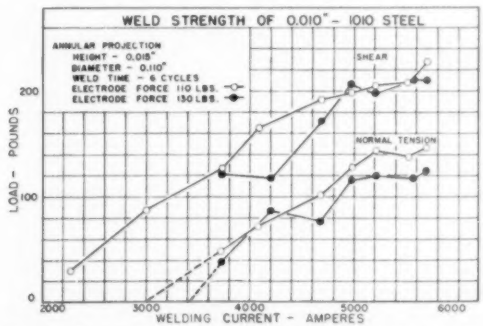


Fig. 11 Strength of welds in 0.010-in., 1010 steel, using 0.110-in. diameter, 0.015-in. height annular projection at 110 lb. and 130 lb. electrode force

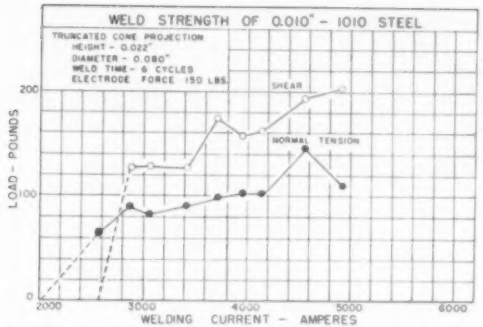


Fig. 12 Strength of welds in 0.010-in., 1010 steel, using 0.080-in. diameter, 0.022-in. height truncated cone projections

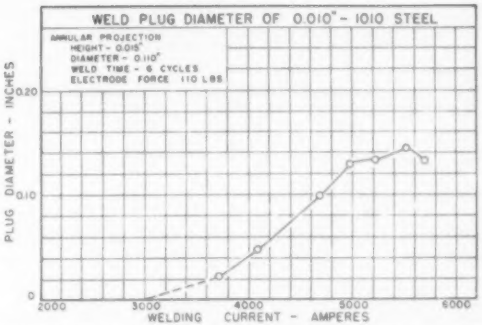


Fig. 14 Weld plug diameter of welds in 0.010-in., 1010 steel, using 0.110-in. diameter, 0.015-in. height annular projection

0.110-in. diameter annular projection at 110 lb. electrode force but the results were erratic and there was no range of current over which the strength remained fairly constant. The inconsistent results are probably caused by extrusion of the projection metal into a collar around the weld. This condition does not add to the weld strength and is to be expected when using a projection with a high height to diameter ratio and steep sides.

The normal to shear ratio for the 0.110-in. diameter annular projection at 110 lb. electrode force, as shown in Fig. 13, varies between 50 and 70% in the normal welding range. The plug diameter of welds, pulled in normal tension, made under these same welding conditions are shown plotted as a function of welding current in Fig. 14.

From these results the optimum welding conditions were determined:

Projection—Annular 0.110 in. diameter, 0.015 in. height
Electrode Force—110 lb.
Weld Time—6 cycles
Weld Current—5000 to 5400 amp.

Using the welding conditions of 5200 amp. per weld, 110 lb. electrode force per weld and 6 cycles weld time, multiple weld tests were made. The best weld spacing

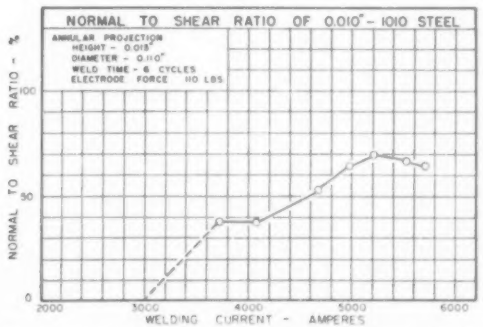


Fig. 13 Normal strength to shear strength ratio of welds in 0.010-in., 1010 steel, using 0.110-in. diameter, 0.015-in. height annular projection

was determined by making double welds at spacings of 0.2, 0.3 and 0.5 in., then testing in both shear and normal tension. As for the 0.020-in. sheet, the shear tests were made for welds aligned in both the axial and transverse direction. The results of these tests, given in Table 6, show that the strength of two welds, increases as the weld spacing increases up to the maximum spacing investigated.

Table 6—Effect of Weld Spacing on Weld Strength of Double Welds, 0.010-In. Thick A.I.S.I.-1010 Steel

Weld spacing, in.	*Shear strength, lb.*		*Normal strength, lb.*
	Axial	*Transverse*	
0.2	276	293	184
0.3	311	316	199
0.5	337	375	194

For the 0.5-in. weld spacing the normal tension strength has just begun to drop while the shear strength is still increasing slightly. Therefore, using a weld spacing of 0.5 in., five specimens each of three and four welds were made for shear and normal tension tests. As with the 0.020-in. sheet, the welds in the three-weld specimens were located at the vertices of a 0.5-in. equilateral triangle with one base perpendicular to the long dimension of the specimen. The welds in the four-weld specimens were located at the corners of a 0.5-in. square having an edge parallel to the long direction of the specimen.

The results, given in Table 7 and plotted in Fig. 16, show that as the number of welds per group is increased, the strength per weld decreases and that the decrease in strength is more pronounced for the normal tension tests. The decrease in strength is not as great proportionally for the 0.010-in. sheet as for the 0.020-in. sheet, as may be seen by comparing Tables 4 and 7 and Figs. 8 and 16.

Figure 15 shows a cross section at 50 × of a weld made between two 0.010-in. thick steel sheets using the recommended welding conditions. The rolling direction of the top sheet is parallel to the page, while that of the bottom sheet is perpendicular to the page. The

Table 7—Multiple Weld Strength, 0.010-In. Thick A.I.S.I.-1010 Steel, 0.5-In. Weld Spacing

Number of welds	Shear strength, lb.		Normal strength, lb.	
	Total	Per weld	Total	Per weld
1	205	205	142	142
2	337	168.5	194	97
3	505	168.3	263	87.7
4	609	152.2	337	84.2

outline of the fused zone of welds in these thin sheets is not clearly defined, however the structure of the metal along the interface is dendritic. The definition of the fused nugget is obscured by inclusions and so-called zones of "incipient melting."

It is believed that these zones of "incipient melting" are actually patches of martensite in the ferrite matrix caused by diffusion of carbon from carbide particles on heating. The time of weld is sufficiently short so that the carbon cannot diffuse very far and forms zones around the carbide particles of higher than average carbon content. When the weld is rapidly cooled at the end of welding these high carbon zones transform to martensite. The photomicrographs at 1500× in Fig. 15 show various stages in the solution of the carbide particles. Photograph A shows two carbide particles just beginning to dissolve. It is about 0.010 in. from the weld-fused zone. Photograph B shows a carbide particle about 0.005 in. from the weld zone which is approximately half dissolved. Photograph C shows a patch of martensite, about 0.002 in. from the weld zone, which resulted from the complete solution of a carbide particle. Microhardness tests on these martensite

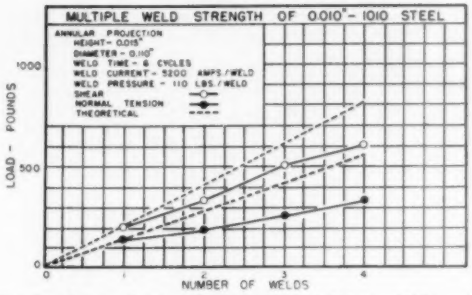


Fig. 16 Strength of multiple welds in 0.010-in., 1010 steel, using 0.110-in. diameter, 0.015-in. height annular projections

zones indicated a hardness of 435–460 VPN compared with 105–115 VPN for the surrounding ferrite.

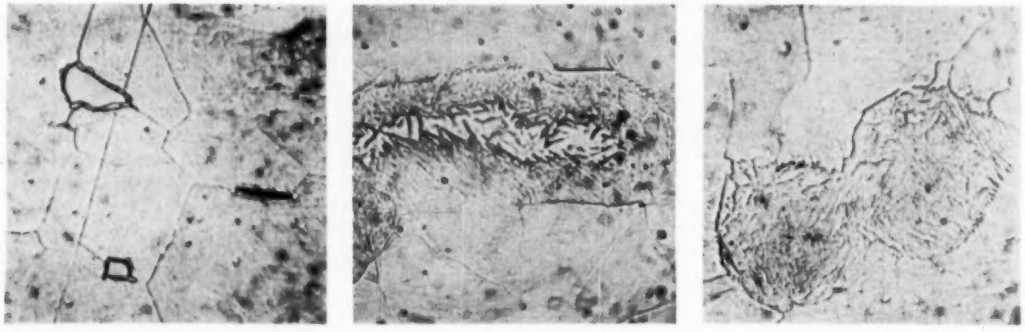
To verify the presence of free carbide particles in this steel, characteristic etching tests were used. Boiling alkaline sodium picrate colored the particles a greenish yellow and a boiling ferricyanide solution blackened the particles. The alkaline sodium picrate colors carbides and dissolves FeS, MnS, FeO and MnO. The ferricyanide solution blackens carbides but leaves nitrides unchanged.

WELDING CONDITIONS FOR OTHER SHEET THICKNESSES

The conditions recommended for welding A.I.S.I.-1010, 1015, and 1020 steels in thicknesses from 0.010 to 0.125 in. are summarized in Table 5. The values

Weld in 0.010-in. sheet. Annular projection, 0.110 in. diameter, 0.015 in. height, 5200 amp., 6 cycles, 110 lb. electric force

Complete weld, × 50



A B C

Stages in solution of carbides. × 1500, reduced by 20% in reproduction

Fig. 15 Microsections of weld in 0.010-in., 1010 steel

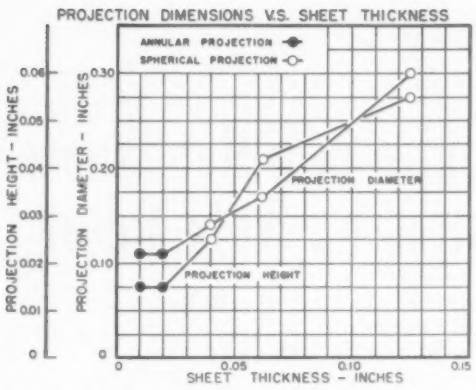


Fig. 17 Variation of projection dimensions for sheet thicknesses from 0.010 to 0.125 in.

given for the 0.040, 0.062 and 0.125 in. thicknesses were given in two previous reports[1, 2] on projection welding originating from this laboratory. In Fig. 17, projection height and projection diameter are plotted against sheet thickness. The projection diameter varies almost directly as the sheet thickness while the projection height increases at a decreasing rate as sheet thickness increases. Figure 18 shows cross sections drawn to scale of the recommended projections for 0.10- to 0.125-in. thick sheets.

CONCLUSIONS

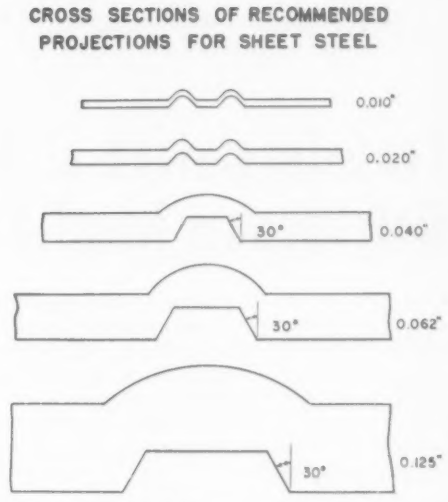
1. In welding 0.010- and 0.020-in. thick steel sheet it was found that an annular shaped projection, 0.110 in. diameter and 0.015 in. high, had the best resistance to cold collapse and at the same time produced symmetrical and consistent welds.

2. The movable electrode must have a sufficiently rapid follow-up to maintain the correct welding force as the projection collapes during the weld cycle. For the light forces used on these thin gages, a spring-loaded electrode is recommended.

3. A low conductivity electrode tip material must be used to keep heat loss to the electrodes to a minimum. Copper-tungsten type electrodes (R.W.M.A. Group B, class 11 or 12), with conductivities of 28–30% I.A.C.S., were found to give the best results.

4. To obtain consistent clean welds with a minimum of expulsion and electrode sticking the sheet surface must be clean before welding.

5. When multiple welds are made in 0.010- or 0.020-in. thick A.I.S.I.-1010 steel, a weld spacing of 0.5 in. will give the best strength. The strength of a group of multiple welds is always less than the number of welds in the group times the strength of a single weld.



SHEET THICKNESS IN.	PROJECTION DIAM. IN.	PROJECTION HEIGHT IN.	PUNCH TOP DIAM. IN.	PUNCH HEIGHT IN.
0.010	0.110	0.015	(SEE FIGURE 3)	
0.020	0.110	0.015	(SEE FIGURE 3)	
0.040	0.140	0.025	0.058	0.035
0.062	0.170	0.042	0.094	0.045
0.125	0.300	0.055	0.176	0.058

Fig. 18 Cross sections of projections for 0.010- to 0.125-thick sheets

FUTURE WORK

Work planned for the immediate future will be the projection welding of similar thicknesses of 0.187- and 0.250-in. thick steel. This will complete the data for projection welding like thicknesses of steel from 0.010 to 0.250 in. thick.

The next phase of the program will be the projection welding of dissimilar thicknesses in the combinations which are possible with 0.010-, 0.020-, 0.040-, 0.062-, 0.125-, and 0.250-in. sheet.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the Welding Research Council for sponsoring this investigation. They are also indebted to the Resistance Welding Committee and the Subcommittee on Projection Welding for their guidance. They wish to thank the Carnegie-Illinois Steel Corp. for supplying steels and the P. R. Mallory Co. for supplying electrode materials used in this investigation.

References

1. Hess, W. F. and Childs, W. J., "A Study of Projection Welding," The Welding Journal, **27** (12), Research Suppl., 712-s to 732-s (1947).
2. Hess, W. F., Childs, W. J., and Underhill, R. F., Jr., "Further Studies in Projection Welding," *Ibid.*, **28** (1), Research Suppl., 15-s to 23-s (1949).

Transformation of Austenite in a Manganese-Molybdenum Steel Deposited as Weld Metal*

The isothermal transformation diagram of a manganese-molybdenum steel deposited as weld metal has been determined; from it a cooling transformation diagram has been derived and correlated with cooling rates in typical weld deposits and in heat-treated steel plate. Supplementary data for this weld metal comprise the hardness and microstructure of an end-quenched hardenability bar, Ae_3 and Ae_1 temperatures, and calculated Ms temperature

by O. O. Miller, F. C. Kristufek and R. H. Aborn

INTRODUCTION

THE familiar isothermal transformation diagram[1, 2†] (I-T diagram, TTT diagram or S-curve) shows quantitatively, for a particular steel, the time required for austenite to transform at different temperatures and provides, in principle, a sound basis for understanding and planning welding cycles for the steel. It also aids greatly in understanding the complex behavior and microstructure resulting from the numerous heating and cooling cycles involved in welding, especially in low-alloy steel base and weld metals,[3] and can be used to prescribe suitable preheat and postheat procedures.[4]

I-T diagrams are available for many wrought, and for a few cast, steels[5] but none has been published for metal deposited by welding. Since it has been shown[6] that austenite transforms in substantially the same way in cast and in wrought steels of the same general composition one might, as a first approximation, take an I-T diagram for a wrought steel as correct for weld metal of corresponding composition, but, unfortunately, such diagrams are available for only a few of the low-carbon, low-alloy steels currently used as welding electrodes.

We have therefore determined the I-T diagram of weld metal of manganese-molybdenum steel, which has unusually great toughness and resistance to shock, with the aim of explaining, and of suggesting means for improving, this notable performance.

O. O. Miller and **R. H. Aborn** are connected with the Research Laboratory, United States Steel Corp. of Delaware, Kearny, N. J.
F. C. Kristufek is connected with Columbia Steel Co., Torrance, Calif.

Scheduled for presentation at 31st Annual Meeting, A. W. S. Chicago, Ill., week of Oct. 22, 1950.

* The results described herein are a portion of those obtained on a project sponsored by the National Defense Research Committee of the Office of Scientific Research and Development and assigned to the Research Laboratory, United States Steel Corporation, Kearny, N. J.

† Numbers in superscript position refer to appended bibliography.

MATERIAL AND EXPERIMENTAL PROCEDURE

The weld metal for this investigation was taken from a pad, $4^1/_4$ x $12^1/_2$ x $1^3/_8$ in., built up on a piece of low-alloy steel plate, 8 x 16 x $1^1/_2$ in., by superimposing successive deposits made with manganese-molybdenum steel electrodes covered with a special low-hydrogen, type of coating corresponding approximately to the present E9015 class. Each pass was deposited parallel to the longest dimension of the pad and with a welding procedure essentially similar to that described in Table 4.

Weld metal from the top, sides and ends of the pad was removed to a depth of $^1/_4$ in. and from the surface adjacent to the base plate to a depth of $^3/_8$ in. because its chemical composition might not be representative of the pad as a whole. The chemical composition was substantially the same at six locations in the remainder of the pad, as shown in Table 1, and is believed to be representative of those portions of the pad which were used in this investigation.

The very small differences in composition among the various portions of the pad indicate that the weld passes were deposited under fairly constant conditions resulting in weld metal as uniform in composition as could be expected. Considerable microsegregation would be expected in the cast metal which comprises the weld-metal passes; this type of segregation is indicated by some differences in microstructure in different areas of each specimen and has been taken into consideration by: (1) evaluating the average condition in each specimen; and (2) basing results on a series of specimens.

For determining the isothermal transformation behavior of austenite in weld metal, it is desirable to start with the austenite approximating, as nearly as possible, its condition when formed by rapid reheating by subsequent deposits in multiple-pass welds. This problem was solved by investigating the effect of different heating rates, austenitizing times and cooling rates on

Table 1—Chemical Composition of Manganese-Molybdenum Steel Weld Metal

Location in pad*	Chemical composition, % C	Mn	Si	Mo	Al	Al_2O_3	O	N
N1	0.10	1.63	0.21	0.42	...	...	...	...
N2	0.10	1.66	0.23	0.41	0.013	0.041	...	...
N3	0.10	1.64	0.19	0.41	...	...	...	...
N4	0.09	1.60	0.19	0.42	...	...	...	...
N5	0.10	1.63	0.22	0.41	0.013	0.042	...	...
N6	0.11	1.64	0.21	0.41	...	...	...	...
Avg. for pad	0.10	1.63	0.21	0.41	0.013	0.042	0.041†	0.011†

* Locations N1, N2 and N3 are approximately 4 in. from one end and are, respectively, 1/4 to 1/2 in., 1/2 to 3/4 in. and 3/4 to 1 in. below the original top surface. Locations N4, N5 and N6 are identical to N1, N2 and N3 except that they are approximately 4 in. from the other end of the pad. Each sample comprised chips produced from milling a volume of metal 1/4 in. deep by 5/8 in. wide by 3 3/4 in. long.

† Determinations made at another time from a single location.

specimens of the weld metal until we obtained a microstructure and prior austenite grain size which approximated those in the weld metal recrystallized by subsequent passes in multiple-pass welds. The desired microstructure, comprising approximately 80% ferrite and 20% martensite in a Widmanstätten type of arrangement, was produced by cooling in still air after the following austenitizing procedure which was subsequently adopted for determining the I-T diagram:

Size of specimen.....1/16 x 3/8 x 7/16 in.
Time to reach 2000° F in silver bath.....2 sec.
Austenitizing time at 2000° F.....20 sec.

No evidence of undissolved carbides was found in specimens austenitized for five or more seconds at 2000° F.

For the standard A.S.T.M. end-quench hardenability test, the specimen was austenitized for 4 hr. at 1700° F. in cast-iron chips to produce an austenite grain size similar to that produced in 20 sec. at 2000° F. Subsequent examination indicated no significant amount of carburization or decarburization during austenitizing.

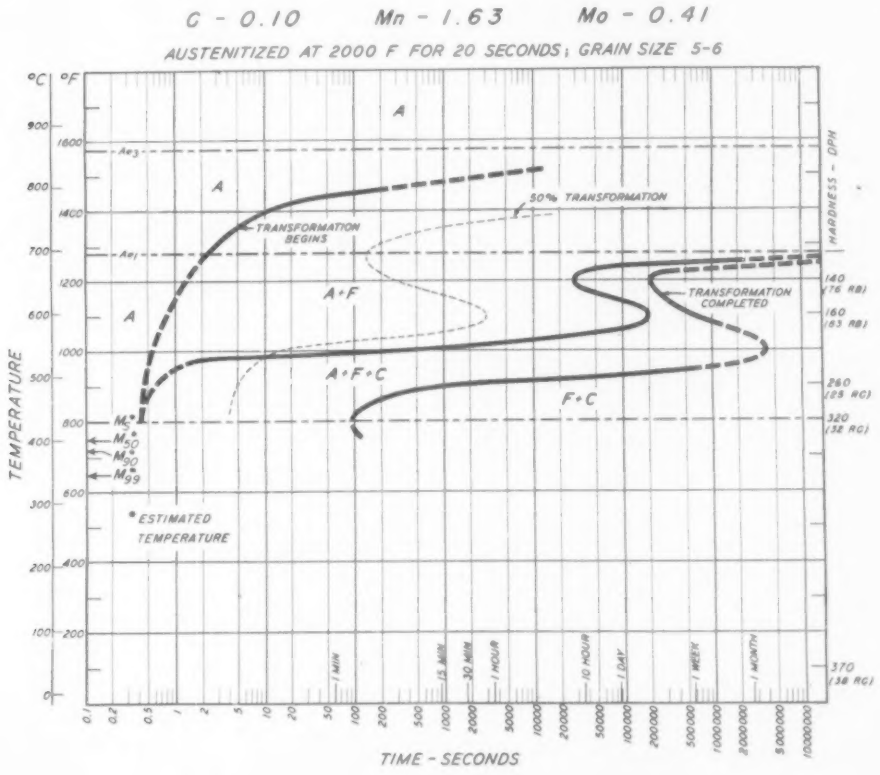


Fig. 1 Isothermal transformation diagram of manganese-molybdenum steel weld metal

ISOTHERMAL TRANSFORMATION DIAGRAM AND SUPPLEMENTARY DATA

The isothermal transformation diagram of this weld metal, given in Fig. 1, was determined by austenitizing specimens as described above, cooling rapidly to the appropriate temperature level for transformation and following the progress of transformation by the well-known microscopic method. In the temperature range between 1250 and 1000° F., transformation to ferrite begins in a very short time and proceeds rapidly, especially in the neighborhood of 1000° F.; in this temperature range a long time is required for the initial appearance of the carbide phase and a very long time is necessary for the completion of transformation.

The microstructures of the weld metal after partial transformation isothermally at temperatures of 1200, 1100, 1000, 900 or 800° F. are shown in Fig. 2.‡ The acicular§ nature of the ferrite formed at 1100 and 1000° F. in contrast to its equiaxed or blocky shape at 1200° F. is noteworthy. Estimates of the percentage of transformation emphasize the tendency for very rapid formation of ferrite without carbide in the neighborhood of 1000° F. Transformation is even faster at 900 and 800° F. to yield bainite.

The following measurements have been made on the weld metal for use in conjunction with the transformation studies:

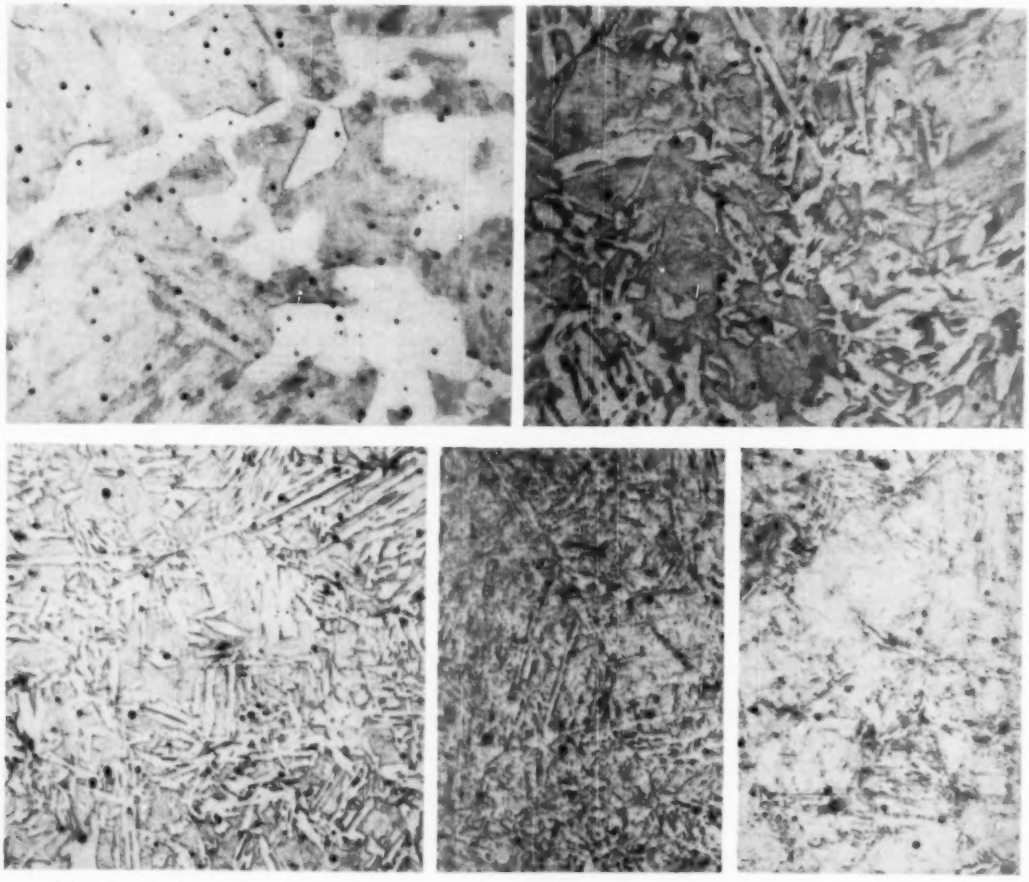
Ae_3 temperature = 1575 ± 10° F.
Ae_1 temperature = 1280 ± 5° F.
Austenite grain size (A.S.T.M.) = 5 to 6 (after 20 sec. at 2000° F.)
Austenite grain size (A.S.T.M.) = 5 to 7 (after 4 hr. at 1700° F.)
Maximum hardness of martensite = 380 DPH (39 RC)

‡ Limitation in reproduction of micrographs in Fig. 2 in some cases may suggest the presence of dark-etching ferrite-carbide aggregates at 1200, 1100 and 1000° F.; this is erroneous because ferrite and martensite are the only constituents present.

§ The word "acicular" is used to describe the characteristic appearance of this Widmanstätten type of arrangement of ferrite and martensite, though the structure is comprised of interlocking plates of the two constituents.

1200° F.: Blocky ferrite and martensite

1100° F.: Acicular ferrite and martensite



1000° F.: Acicular ferrite and martensite

900° F.: Bainite and martensite

800° F.: Bainite and martensite

Fig. 2 Microstructure of manganese-molybdenum steel weld metal partially transformed isothermally at the temperatures indicated. × 1000. Etchant: Picral

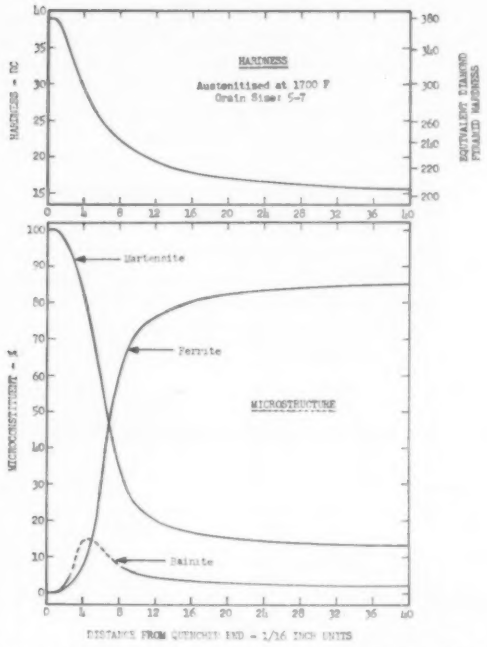


Fig. 3 Hardness and microstructure of end-quenched hardenability bar of manganese-molybdenum steel weld metal

DISCUSSION OF RESULTS

The tendency to form acicular ferrite in a Widmanstätten structure comprising chiefly ferrite and martensite appears to be greater for this weld metal than for most other low-carbon steels, for which I-T diagrams have been determined at this Laboratory, as indicated by the data in Table 2. For some of these steels, especially those containing an appreciable percentage of nickel, the Ae_1 temperature is considerably lower than for this weld metal; consequently, for these steels the comparison of structures formed at the same temperature level is not strictly valid, although it is believed that the correct trend is indicated. At any given temperature, transformation products from coarse-grained austenite appear more acicular than those from fine-grained austenite; however, this fine-grained weld metal gives a more acicular ferrite than coarse-grained molybdenum steel or chromium-silicon-copper-phosphorus steel. The fact that the weld metal is cast, whereas the other steels in Table 2 are wrought, may have some bearing on the shape of the ferrite observed. Related work[7] indicates that manganese may contribute strongly to the formation of a Widmanstätten arrangement of martensite and acicular-shaped ferrite and the weld metal is relatively high in manganese, as shown in Table 1.

The highest temperature, M_s, at which the first trace of martensite forms in a steel on the rapid cooling of

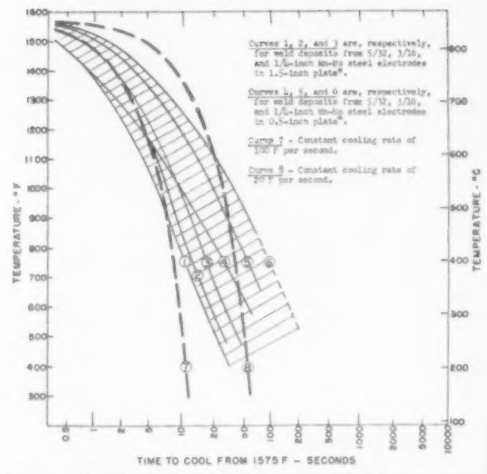

Curves 1, 2, and 3 are, respectively, for weld deposits from 5/32, 1/16, and 1/8-inch Mn-Mo steel electrodes in 1.5-inch plate*.
Curves 4, 5, and 6 are, respectively, for weld deposits from 5/32, 1/16, and 1/8-inch Mn-Mo steel electrodes in 0.5-inch plate*.
Curve 7 - Constant cooling rate of 100 F per second.
Curve 8 - Constant cooling rate of 20 F per second.
TEMPERATURE - °F
TEMPERATURE - °C
TIME TO COOL FROM 1575 F - SECONDS

Fig. 4 Comparison of cooling of weld deposits from manganese-molybdenum steel electrodes with two constant-rate cooling curves

austenite was calculated approximately from the chemical composition by means of the formula proposed by Grange and Stewart.[8, 9] Although this is an empirical relationship for steels higher in carbon than the weld metal, it is probable that it applies in this case as well. For austenite of the mean composition of the weld metal, M_s is calculated to be 800° F. For pools of austenite assumed to contain 0.4% carbon because of enrichment of austenite by rejection of 75% proeutectoid ferrite, M_s is 605° F.

Thus, it is evident that rejection of ferrite has a substantial influence on the M_s temperature of the remain-

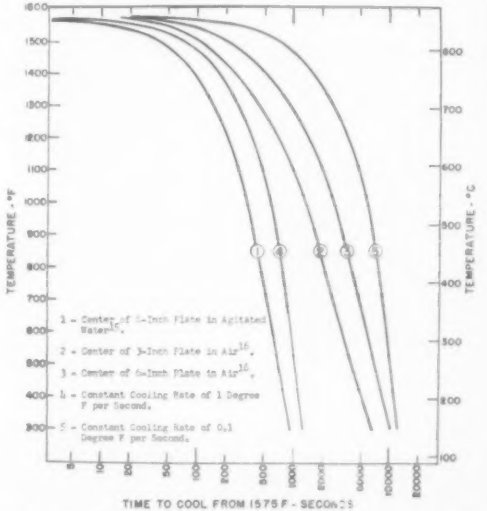

1 - Center of 6-Inch Plate in Agitated Water[15].
2 - Center of 3-Inch Plate in Air[16].
3 - Center of 6-Inch Plate in Air[16].
4 - Constant Cooling Rate of 1 Degree F per Second.
5 - Constant Cooling Rate of 0.1 Degree F per Second.
TEMPERATURE - °F
TEMPERATURE - °C
TIME TO COOL FROM 1575 F - SECONDS

Fig. 5 Comparison of cooling of plates in agitated water or in air with two constant-rate cooling curves

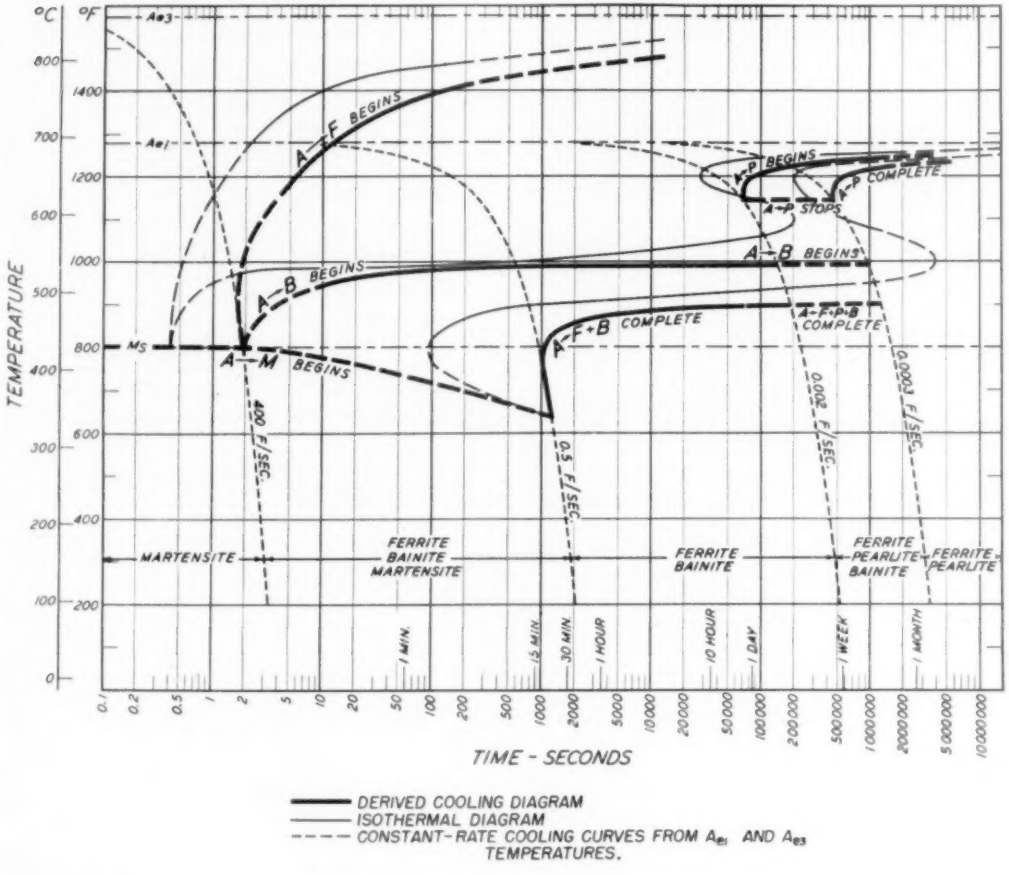
ing austenite. Other work,[8] on a wide variety of medium-carbon low-alloy steels, enables one to estimate that when austenite with the composition of the weld metal is cooled rapidly, approximately 99% of it has transformed to martensite when 650° F. is reached; this is indicated on the I-T diagram in Fig. 1.

The hardness and microstructure of the end-quenched hardenability bar are given in Fig. 3 which shows that the hardenability of the weld metal is relatively low, as would be expected because of the low-carbon content and the corresponding strong tendency to reject proeutectoid ferrite, as shown in Figs. 1 and 2.

Retention of austenite apparently is not a significant factor in the marked toughness of the weld metal because little, if any, is retained. Table 3 shows that retained austenite does not exceed 1%, even in the presence of relatively high-carbon pools of austenite formed during holding at 1000° F. for 50 min. The amount of retained austenite is probably much less than 1%, though we have no experimental means for determining extremely small quantities.

DERIVED COOLING TRANSFORMATION DIAGRAM

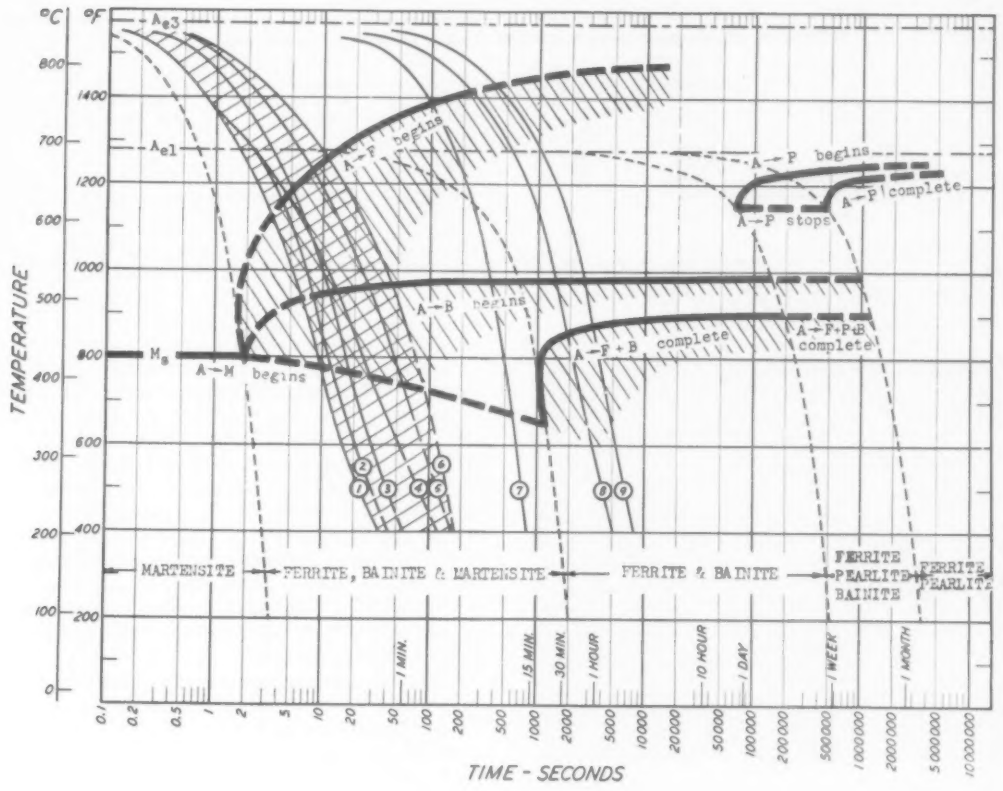
A limitation of the I-T diagram is that it does not indicate accurately the microstructures which result on continuous cooling, such as occurs after weld metal is deposited. It is therefore desirable to have a cooling transformation diagram (C-T diagram) which can be



NOTE 1: A FOR AUSTENITE, F FOR FERRITE, P FOR PEARLITE, B FOR BAINITE, M FOR MARTENSITE

NOTE 2: Ms FOR TEMPERATURE AT WHICH MARTENSITE STARTS TO FORM. Ms IS LOWER AS AUSTENITIC POOLS BECOME RICHER IN CARBON BECAUSE OF REJECTION OF FERRITE ON COOLING; BELOW 800F VALUES FOR Ms ARE APPROXIMATIONS TO SHOW THIS TREND.

Fig. 6 Diagram showing austenite transformation in manganese-molybdenum steel weld metal on cooling at constant rate derived from isothermal diagram



NOTE: A, F, P, B, M and M_s are same as in Fig. 6.
Cooling curves 1, 2 and 3 are, respectively, for weld deposits from ⅛-, 5/32-, and 3/16-in. Mn-Mo steel electrodes in 1.5-in. plate (see Fig. 4). Cooling curves 4, 5 and 6 are, respectively, for weld deposits from ⅛-, 5/32- and 3/16-in. Mn-Mo steel electrodes in 0.5-in. plate (see Fig. 4). Cooling curve 7 is for center of 6-in. plate in agitated water (see Fig. 5). Cooling curve 8 is for center of 3-in. plate in air (see Fig. 5). Cooling curve 9 is for center of 6-in. plate in air (see Fig. 5).

Fig. 7 Cooling curves for weld deposits from manganese-molybdenum steel electrodes and for plates superimposed on derived cooling transformation diagram

either determined experimentally or derived from an I-T diagram. The experimental procedure is difficult in any steel, and practically inoperable in the case of a low-carbon steel. Several means of deriving a C-T diagram from an I-T diagram have been suggested[10, 11, 12, 13] but all are subject to certain assumptions and inaccuracies, though they do give a useful result. We have chosen to use the method described by Grange and Kiefer.[10]

In this method it is necessary to choose a single family of cooling curves; either constant-rate or variable-rate curves may be employed. Constant cooling-rate curves were chosen since these are convenient to use and, for comparative purposes, do not differ greatly from the cooling curves for weld deposits and plates, as illustrated in Figs. 4 and 5. Cooling curves 1 to 6 in Fig. 4 are for weld deposits from three sizes of electrodes in two thicknesses of steel plate. They were derived by taking the data in Table 4 on energy input during welding with manganese-molybdenum steel electrodes and finding the corresponding weld cooling curve for the same electrode size, plate thickness, interpass temperature and energy input given by Hess, Merrill, Nippes and Bunk.[14] The three experimentally determined cooling curves[15, 16] in Fig. 5 are for the center of 6-in. plate quenched in water and for 3- and 6-in. plate cooled in air; these curves are of particular interest in considering the use of this weld metal for the welding of low-alloy steel in form of thick plate which is to be austenitized and quenched after welding.

On this basis, we obtained the C-T diagram presented

Table 2—Microstructures of Low-Carbon Steels Transformed Isothermally

Steel	Ae_1 temperature, °F.	Austenite grain size	Shape of ferrite formed at 1200° F.	1100° F.	1000° F.
0.05 C(Rimmed)	1335	Fine	...	Equiaxed†	Part acicular
Cr-Si-Cu-P*		Part coarse	...	...	Part acicular
S.A.E. 4815	1250	Fine	Equiaxed	...	Part acicular
S.A.E. 3310	1245	Fine	Equiaxed	Equiaxed	Part acicular
S.A.E. 8620	1335	Fine	Equiaxed	Part acicular	...
S.A.E. 2512	1135	Fine	Equiaxed	Equiaxed	Equiaxed§
Mo‡	1330	Coarse	Equiaxed	Acicular	Sharp acicular
Mo‡	1330	Fine	Equiaxed	Part acicular	Blunt acicular
Mn-Mo weld metal	1280	Fine	Equiaxed	Sharp acicular	Sharp acicular

*0.08% C, 0.26% Mn, 0.18% P, 0.73% Si, 1.10% Cr, 0.45% Cu.
† A little elongated.
‡ 0.22% C, 0.8% Mn, 0.5% Mo.
§ Blunt acicular at 900° F.

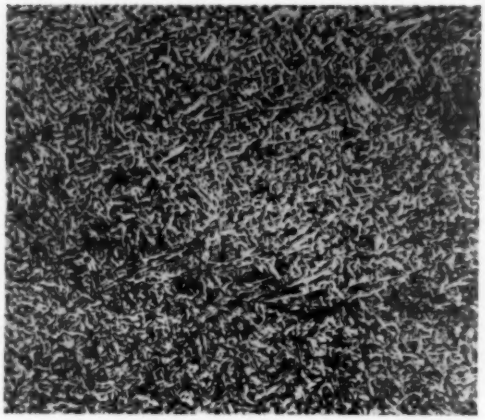


Fig. 8 Typical microstructure of manganese-molybdenum steel weld metal as deposited in a 1.5-in. plate joint made with a 1/4-in. electrode by arc welding Microstructure is a Widmanstätten arrangement essentially of ferrite and martensite. Etchant: picral. × 500

in Fig. 6. It lies to the right and below the I-T diagram. It is modified to take into account the probable influence upon the M_s temperature of carbon enrichment of austenite by rejection of proeutectoid ferrite. Though the M_s is shown as a line, its exact position below 800° F. cannot be calculated with great accuracy and accordingly its position must be regarded as approximate. The microstructures, which form on cooling at different rates are indicated in Fig. 6. The C-T diagram, weld-deposit cooling curves (Fig. 4) and cooling curves for steel plates (Fig. 5) are assembled in Fig. 7 which shows that transformation to pearlite is too slow to be significant in welding with this type of electrode and that attention should be concentrated on transformation to ferrite, bainite and martensite.

It is well known that transformation of austenite, isothermally or on continuous cooling, is influenced by such variables as grain size and carbon content. The effect of these variables on the position of the ferrite and bainite lines of the C-T diagram in Fig. 7 is believed to be approximately as follows:

1. The lines for the beginning and completion of the formation of bainite move to the right and down into the shaded areas, shown in Fig. 7, as a result of carbon enrichment of the austenitic pools if proeutectoid ferrite has been rejected during cooling. This rejection of ferrite was not taken into consideration in deriving the C-T diagram.

2. The bainite lines are displaced to the left as austenite grains become larger, and to the right into the shaded areas as they become smaller; these changes are due to the influence of austenite grain size upon ferrite rejection and the consequent carbon content of the austenitic pools. For specimens of a particular steel differing in grain size, but cooled at the same rate, the carbon content of austenite which reaches bainite-forming temperatures is higher the smaller the austenite grains because more ferrite is rejected during cooling. This effect, also observed in 3312 and 4815 wrought

Table 3—X-Ray Diffraction Study of Manganese-Molybdenum Steel Weld Metal for Traces of Retained Austenite

Source of weld metal	Austenitizing	Cooling	Interpretation of diffraction pattern: Austenite lines	Amount of austenite, %
As-welded 0.5-in. plate	...	...	None	Less than 1*
Pad	2000° F., 20 sec.	Arrested†	None	Less than 1*
Pad	2000° F., 20 sec.	Air to 70° F.	None	Less than 1*
Pad	2000° F., 20 sec.	Oil to 70° F.	None	Less than 1*
Pad	2035° F., 20 sec.	Arrested‡	None	Less than 1*
Pad	2035° F., 20 sec.	Arrested§	None	Less than 1*
Pad	2035° F., 20 sec.	Arrested‖	Very weak	About 1

* There may be no retained austenite; in any event there is not more than 1%. This sensitivity was established by an X-ray diffraction study of high-carbon steels known from metallographic work to contain retained austenite from as little as 1% to as much as 10%.
† Quenched into salt at 500° F., held at 500° F. for 2.5 hr., and quenched to 70° F.
‡ Quenched into lead at 1000° F., held at 1000° F. for 50 min., and air cooled to 70° F.
§ Quenched into lead at 1000° F., held at 1000° F. for 50 min., and oil quenched to 70° F.
‖ Quenched into lead at 1000° F., held at 1000° F. for 50 min., and brine quenched to 70° F.

Table 4—Energy Input During Welding with Manganese-Molybdenum Steel Electrodes

Electrode size in.	Preheat and maximum interpass temperature, °F.	Average Arc Conditions* Current, amp.	E.M.F., v.	Speed, in./min.	Energy input, joules/in.
5/32	200	175	22	7	33,000
3/16	200	220	24	7	45,000
1/4	200	325	25	7	70,000

* These are the arc conditions recommended by one of the manufacturers of manganese-molybdenum steel electrodes, when the proper size of electrode is selected to fill the space in the groove. Direct current is employed and the electrode is positive.

steels, is opposite to the well-known effect of austenite grain size on the position of the ferrite line in I-T and C-T diagrams.

3. This type of manganese-molybdenum steel weld metal frequently contains approximately 0.15% carbon in place of the 0.10% in the pad used for this work. If carbon content is greater than 0.10%, the beginning lines for ferrite and bainite, and possibly the completion line for bainite, move into the shaded areas.

This shifting of the lines into the shaded areas is, of course, accompanied by changes in microstructure for the same cooling rate; for example, when the nominal carbon content is higher, with consequent shifting of ferrite and bainite beginning lines to the right, the zone labeled *Martensite*, Fig. 7, becomes wider. No method exists at present for estimating the correct location of the lines in the shaded areas.

The shift of the bainite beginning line to the right and downward makes possible structures consisting essentially of ferrite and martensite in the weld metal as deposited, as is evident from the position of weld-metal cooling curves 1 to 6 in Fig. 7. A typical microstructure of manganese-molybdenum steel weld metal, as deposited in the last pass of a multiple-pass weld in 1.5-in. plate, is shown in Fig. 8; it is frequently not significantly different from Fig. 8 when recrystallized by subsequent passes in a weld of this type.

Cooling curves 7, 8 and 9 in Fig. 7 represent the much slower cooling of the center of the 3- and 6-in. plates; as mentioned above, these curves are of interest in relation to use of the weld metal in welding of thick plate. Obviously, the hardenability of the weld metal is too low for such an application, if a microstructure of tempered martensite is desired.

ACKNOWLEDGMENT

The authors gratefully acknowledge the assistance of D. S. Miller in making the X-ray diffraction studies and of General Motors Corp., Grand Blanc, Mich., for making the pad of weld metal.

SUMMARY

The isothermal transformation diagram of manganese-molybdenum steel weld metal in Fig. 1, the accompanying micrographs in Fig. 2 and the end-quench hardenability data in Fig. 3, constitute a summary of the experimental work. The derived cooling transformation diagram is given in Fig. 6 and a somewhat schematic modification is shown in Fig. 7 with superimposed cooling curves for: (*a*) manganese-molybdenum steel weld metal deposited from 5/32-, 3/16- and 1/4-in. electrodes in both 0.5- and 1.5-in. plates; (*b*) 6-in. plate quenched in agitated water; and (*c*) 3- and 6-in. plates cooled in air. A typical example of the microstructure of the weld metal, as deposited, is shown in Fig. 8.

Two observations have been made which are believed to be related to the relatively great toughness and shock resistance of this weld metal:

1. The tendency to form acicular ferrite, in a Widmanstätten structure consisting essentially of ferrite and martensite, is very great for this manganese-molybdenum steel weld metal. Experience indicates that acicular microstructures, whether in weld metal or base metal, are generally associated with a toughness superior to that of equiaxed microstructures. In multiple-pass welds a very strong tendency to retain the acicular microstructure has been observed when this weld metal is reheated by subsequent weld passes. It appears probable that the considerable percentage of manganese in this weld metal is a significant factor in producing this structure.

2. The rapid and extensive formation of acicular ferrite, in the approximate range 900 to 1100° F., so enriches the residual austenitic pools in carbon that, in the relatively fast cooling that occurs in welds, these pools are largely retained through the intermediate temperature range and, as a consequence, transform largely to martensite instead of to bainite (see Figs. 7 and 8). This is believed to be advantageous because other investigations indicate that microstructures consisting of ferrite and martensite (and/or probably lower bainite) have much greater toughness and shock resistance than those consisting of ferrite and upper bainite or pearlite, assuming that the amount of free ferrite is about the same in both cases.

Bibliography

1. Davenport, E. S., "Isothermal Transformation in Steels." *Trans. Am. Soc. Metals*, **27**, 837 (1939).
2. "Atlas of Isothermal Transformation Diagrams," U. S. Steel Corp. of Delaware, Pittsburgh, Pa., 1943.
3. Aborn, R. H., "Metallurgical Aspects of the Welding of Steel," THE WELDING JOURNAL, **19** (10), Research Suppl., 414-s to 426-s (1940).
4. Browne, Jr., L. F., "The Use of Direct Transformation Data in Determining Preheat and Postheat Requirements for Arc Welding Deep-Hardening Steels and Weld Deposits," *Ibid.*, **25**, (4) Research Suppl., 234-s to 241-s (1946).
5. Morral, F. R., "Heat Treating Diagrams—S or TTT-Curves," *Metal Progress*, **48**, 818 (1945).
6. Eddy, C. T., Marcotte, R. J., and Smith, R. J., "Time-temperature Transformation Curves for Use in the Heat-treatment of Cast Steel," *Trans. Am. Inst. Mining Met. Engrs.*, **162**, 250 (1945).
7. Miller, O. O., Kristufek, F. C., and Aborn, R. H., "Development of Ferritic Weld Metal for Repair of Thick Cast Armor. Part I—Investigation of Thirteen Preliminary Experimental Weld Metals," NDRC Report M-631 (OSRD 6366), Dec. 5, 1945. Declassified to *OPEN*. (Can be ordered from Office of Technical Services, U. S. Department of Commerce).

8. Grange, R. A., and Stewart, H. M., "The Temperature Range of Martensite Formation," *Trans. Am. Inst. Mining Met. Engrs.*, **167**, 467 (1946).
9. Payson, P., and Grange, R. A., "The Temperature Range of Martensite Formation in Steel," *Metals Handbook*, American Society for Metals, Cleveland, Ohio, 1948 ed. p. 611.
10. Grange, R. A., and Kiefer, J. M., "Transformation of Austenite on Continuous Cooling and Its Relation to Transformation at Constant Temperature," *Trans. Am. Soc. Metals*, **29**, 85 (1941).
11. Steinberg, S., "Relationship between Rate of Cooling, Rate of Transformation, Undercooling of Austenite and Critical Rate of Quenching," *Metallurgy*, **13** (1), 7 (1938).
12. Hoyt, S. L., "The Weldability of Casing Steels," Paper presented at meeting of Am. Pet. Inst., New Orleans, La., May 18, 1939.
13. Manning, G. K., and Lorig, C. H., "The Relationship between Transformation at Constant Temperature and Transformation during Cooling," *Trans. Am. Inst. Mining Met. Engrs.*, **167**, 442 (1946).
14. Hess, W. F., Merrill, L. L., Nippes, Jr., E. F., and Bunk, A. P., "The Measurement of Cooling Rates Associated with Arc Welding and Their Application to the Selection of Optimum Welding Conditions," WELDING JOURNAL, **22** (9), Research Suppl., 377-s to 422-s (1943).
15. Data supplied by Watertown Arsenal to National Research Council.
16. Data supplied by Battelle Memorial Institute to Office of Scientific Research and Development.

Stress-Corrosion Cracking of Mild Steel

Discussion by R. N. Parkins

The authors are to be congratulated in adding to the increasing amount of data available on the stress-corrosion cracking of mild steel, particularly in the field of the influence of the corrosive environment, where systematic information is lacking.

In the conclusions reached from the present work they state "it is possible that the cold working of the metal acted as a preventative to stress-corrosion," which would appear to be in contradiction to the findings of the majority of other workers in this field.[1-3] It would appear, however, on a closer examination of the results given, that such a conclusion is not justified, since, after removing the cold-working effect due to drawing by heat treatment, the stress applied during the corrosion test is frequently above the yield point of the material (cf. Tables 1 and 2). The material then must be in a cold-worked condition during corrosion, the difference between the two cases merely being in the degree of plastic deformation which the metal undergoes.

Apparently then, small degrees of cold work do not inhibit failure while the considerable amount of plastic deformation undergone during wire drawing has the opposite effect. The explanation of this phenomenon may well lie in the results which show the effect of annealing subsequent to cold working and prior to corrosion testing, and the effect which these treatments are likely to have upon the microstructure.

R. N. Parkins, Department of Metallurgy, University of Durham, Newcastle Upon Tyne, 1, England.

Paper by D Cubicciotti and William Boyer was published in the *Research Supplement* to the March, 1950, WELDING JOURNAL, pp. 140-s to 145-s.

Thus in the cold drawn state the microstructure is likely to be so severely distorted that the conditions within the grain boundaries which normally lead to stress-corrosion cracking no longer exist. Annealing at 600° C., which should be above the recrystallization temperature, would be expected to render the material susceptible to stress corrosion again if nitride precipitation was the cause of the phenomenon, since recrystallization and precipitation would be expected to occur at this temperature. It may be significant, however, that only when the carbide precipitation temperature has been passed does the susceptibility return, i.e., only when the annealing temperature exceeds 725° C. with the subsequent change in distribution of the cementite does cracking recur. The effect of a small amount of plastic deformation on the annealed microstructure will be negligible in comparison with the change likely on cold drawing.

References

1. Weber, J. T., and McDonald, H. J., *Stress-Corrosion Cracking of Mild Steel*, Corrosion Publishing Co., Pittsburgh, Pa., 1947.
2. Houdremont, E., Beneck, H., and Wentrup, H., *Stahl u. Eisen*, **60**, 573 (1940).
3. Pearson, C. E., and Parkins, R. N., *Trans. Inst. Welding (London), Welding Research*, **3**, (6) 952 (1949).

Authors' Reply

The suggestion of R. N. Parkins that the microstructure of the cold-drawn wire is so severely distorted that stress corrosion does not occur and that recrystallization above the carbide precipitation temperature revives stress corrosion susceptibility is very interesting. I would like to add to this suggestion the idea that very probably it is the surface condition of the wire that determines susceptibility to stress corrosion since it is at the surface that the cracking must begin. Therefore an investigation of the relationship between microstructure and susceptibility to cracking might well be directed toward a study of the surface structure as well as the body structure of the metal.

Effect of Low-Temperature Cooling Rate on the Ductility of Arc Welds in Mild Steel

The ductility of E6010 welds depends on the rate at which the cooling weld traverses temperatures below 400° F., rapid cooling promoting low ductility. This behavior, to which low-hydrogen welds appear immune, has important practical implications

by A. E. Flanigan, S. I. Bocarsky and G. B. McGuire

1. INTRODUCTION

IT HAS long been realized that the ductility of an arc weld in mild steel is influenced by the rate at which the cooling weld traverses temperatures in the region of 1000° F. Such "elevated-temperature" cooling rates are believed to affect the nature of the austenite transformation and their influence has been widely studied. While less attention has been given to the possibility that ductility may also be affected by the rate at which the weld cools through lower temperatures, there have been indications that these "low-temperature rates" may also be significant.[1,2] The work of Bland is of particular importance.

During the past two years, three theses[3, 4, 5] have been written at the University of California on the subject of low-temperature rates. They show that weld ductility is strongly affected by the rate of cooling even at temperatures well below 400° F. and they suggest that this influence is one of considerable practical importance. They show also that the hydrogen content of the weld is, in part at least, responsible for the phenomenon. The results are generally consistent with those of Bland.

The present paper is based in the main on the investigations reported in the theses. An extension of the work, now in progress,* will be described in a later paper.

2. THE BEND TEST

Throughout the paper, ductility measurements are reported in terms of a longitudinal notched-bend test conducted at −100° F. A typical test specimen is shown in Fig. 1. It consists of a bead-on-plate weld deposited along the major center line of a 4 x 9 x $^3/_8$-in. blank previously flame cut from a large plate. The axis of the weld lies in the direction of rolling. The transverse notch, prepared with a $^1/_8$-in. convex milling cutter ($^1/_{16}$-in. radius), is cut to a depth of 0.020 in. below the surface of the plate. At the center line of the weld the notch terminates in the weld metal, the depth of weld penetration being about 0.110 in. under the welding conditions employed.

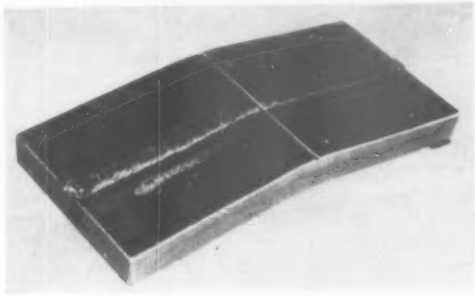


Fig. 1 Bend test specimen

In testing, the specimen was bent as a centrally-loaded simple beam with the notched side in tension. The bending fixture, shown in Fig. 2, employs a 6-in. spacing between supports. Bending was accomplished at a cross-head speed of 0.4-in. per minute and was continued up to the sudden and complete fracture of the specimen, the bend angle attained at fracture being taken as the measure of ductility.

During testing, the specimen and the fixture were surrounded by an alcohol bath at −100° F. (The alcohol tank is not shown in Fig. 2.) Reasons for conducting the tests at this low temperature are described in Section 11.

A. E. Flanigan is Associate Professor of Engineering, University of California, Los Angeles, Calif.; **S. I. Bocarsky** is Open Hearth Observer, Bethlehem Pacific Coast Steel Corp., Los Angeles, Calif. and **G. B. McGuire** is Research Analyst, North American Aviation Corp., Downey, Calif.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

* The thesis research and the current extension have been supported by grants from the Welding Research Council of the Engineering Foundation and from the Research Committee of the University of California at Los Angeles.

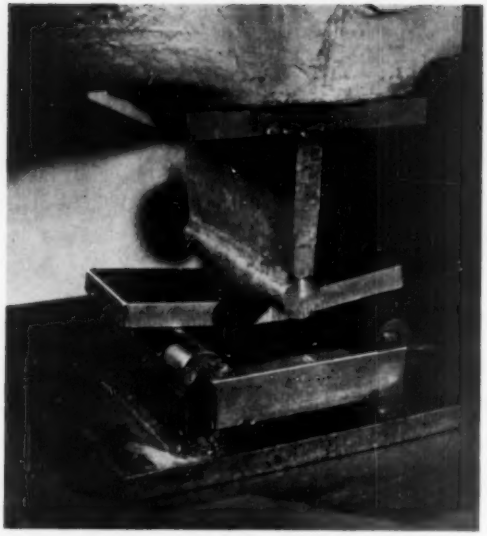


Fig. 2 Fixtures used in bend tests

3. MATERIALS AND WELDING PROCEDURE

The specimens were prepared from two heats of semikilled $^3/_4$-in. A.S.T.M. A285-C firebox quality plate. The chemical analyses and tensile properties of the materials are listed in Tables 1 and 2. The analyses are similar and it is believed that the two heats behaved in essentially similar manners.

Table 1—Chemical Analyses of Plates and Welds

	C	*Mn*	*P*	*S*	*Si*	*N*
plate, 1st heat	0.17	0.38	0.014	0.03	0.03	0.006
plate, 2nd heat	0.19	0.33	0.015	0.03	0.07	0.005
E6010 Weld on 1st heat	0.10	0.40	0.013	0.03	0.15	0.012

All welds, aside from those of Section 8, were deposited with a popular brand of $^3/_{16}$-in. A.W.S. E6010 electrodes. A chemical analysis of the weld metal is included in Table 1.

Table 2—Tensile Properties of the Steel

	1st heat	*2nd heat*
Ultimate stress, 1000 psi.	56.6	59.7
Yield point, 1000 psi.	35.7	36.9
Elongation at fracture, per cent in 8 in.	32	28

Prior to welding, the mill scale was ground from the blanks along the path of the weld. Welding was accomplished at 25 v. with a current of 170 amp. and an arc speed of 7.7 in. per minute. Following welding, the specimens were stored at room temperature for a period of from 4 to 5 days before testing.

4. TESTS ON QUENCHED WELDS

To isolate the effect of low-temperature cooling rate

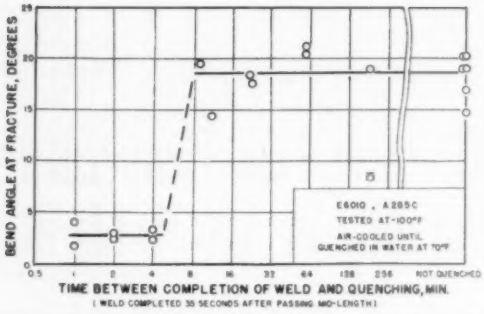


Fig. 3 Influence of quenching following welding on the bend test behavior of E6010 welds

on ductility it was desired to vary these rates without altering those at the temperatures of the austenite transformation. This section deals with one of the several methods which were used to attain this end.

After welding, a group of E6010 specimens was allowed to cool in air† for various periods ranging from one minute to several hours. Air cooling was then interrupted and the specimens were quenched in water at 70° F. Subsequently they were notched and were subjected to bend tests at −100° F.

The results of these tests are shown in Fig. 3. It will be seen that the specimens which had been allowed to cool for 8 min. or longer before quenching fractured at characteristically large values of bend angle, generally greater than 15°. In the case of specimens quenched within 4 min. after the completion of welding, much smaller values of bend angle were attained, all values lying in the range from 2 to 4°.

To aid in interpreting the results of Fig. 3, determinations of weld temperature were made during air cooling following welding. This was accomplished by means of a high-speed autographic potentiometer actuated by a 28-gage chromel-alumel thermocouple. During welding, the couple was inserted in the molten weld at the mid-length of the specimen, the region of the notch in Fig. 1. The resultant cooling curve (based on an average of three determinations) is shown in Fig. 4. Only the upper curve in the figure is of interest at this point, the other referring to a condition to be described in the next section.

From Fig. 4 it may be seen that at the completion of welding (35 sec. after passing mid-length) the weld temperature had reached a value of approximately 400° F. Four minutes later it had fallen to about 325° F. Thus it appears that the low-ductility welds of Fig. 3 were embrittled by rapid cooling from temperatures between 400 and 325° F. Since all of the specimens of Fig. 3 had identical cooling histories at temperatures above 400° F., embrittlement must be attributed to the influence of low-temperature cooling alone.

† Throughout the paper, "air-cooling" signifies cooling in still air at 70° F. with the specimen lying horizontally on a wood surface, welded side uppermost.

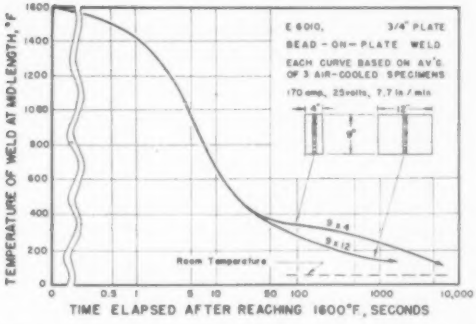

E 6010, 3/4" PLATE
BEAD - ON - PLATE WELD
EACH CURVE BASED ON AV'S. OF 3 AIR-COOLED SPECIMENS
(70 amp, 25 volts, 7.7 in./min
9 x 4
9 x 12
Room Temperature
TEMPERATURE OF WELD AT MID-LENGTH, °F
TIME ELAPSED AFTER REACHING 1600°F, SECONDS

Fig. 4 Influence of specimen width on the cooling rate of the weld

5. TESTS ON WIDE SPECIMENS

In the tests of the preceding section quenching was employed to accelerate cooling in the low-temperature range. Since such treatments are seldom encountered in practice, one may wonder if the behavior exhibited in Fig. 3 is of practical interest. In this connection it is well to remember that, even in the absence of quenching, the low-temperature rates encountered in practice are often more rapid than that which results from the air cooling of a 4- x 9- x $^3/_4$-in. specimen.

One of the factors which would be expected to influence the rapidity of low-temperature cooling is the ratio of the heat capacity of the specimen (a function of size) to the total heat input in welding. For the relatively small specimen of Fig. 1 this ratio is less than that which would result if the same weld were deposited on a more massive specimen. Thus, low-temperature cooling, even in the absence of quenching, would be expected to be more rapid in a larger specimen.

To determine the effect of accelerated cooling obtained through the use of a more massive specimen, a series of 12- x 9- x $^3/_4$-in. specimens was studied. Aside from their increased widths, these specimens were in all respects similar to those of Fig. 1. (See the sketch in Fig. 5.) They were welded in the usual manner with E6010 electrodes and were cooled in air. Later the wide specimens were sawed to a 4-in. width before being tested at −100° F. When tested, they were geometrically identical with the standard specimen.

The results of the tests are shown in Fig. 5 where they are compared with those for the air-cooled standard specimens of Fig. 3. It will be seen that, even in the absence of quenching, the values of bend angle at fracture are strikingly low in the case of the wide specimens.

A comparison of the cooling curves for the 12- and the 4-in. specimens is shown in Fig. 4 where it will be observed that there is practically no difference in rate until a temperature of about 400° F. is reached. At lower temperatures the cooling of the wide specimen is considerably more rapid. For example, it will be noted that the 4-in. specimen requires approximately 10 times as long to cool to a temperature of 200° F.

That the elevated-temperature rates of the two specimens should be similar is of course not unexpected since an appreciable time is required for heat to flow from the region of the weld to the edges of even the 4-in. specimen. During this interval the temperature gradient near the weld, and hence the cooling rate of the weld, is little affected by the width of the specimen. Only during later stages would one expect the cooling rate to be affected.

It is concluded, then, on the basis of Figs. 4 and 5 that the low ductility of the wide specimens must be attributed to the acceleration of low-temperature cooling alone.

6. TESTS ON SHORTER WELDS

In the tests of the preceding section, acceleration of low-temperature cooling was obtained by increasing the ratio of the specimen size to the total heat input in welding. This was accomplished by increasing the specimen size while holding the heat input fixed. A similar increase in the ratio can of course be attained by employing a lower heat input on a specimen of standard size. This section deals with tests of the latter sort, lower heat inputs being obtained by reducing the length of the weld. These tests were intended to check the indications of the preceding section.

E6010 welds of lengths ranging from $2^1/_2$ to 9 in.

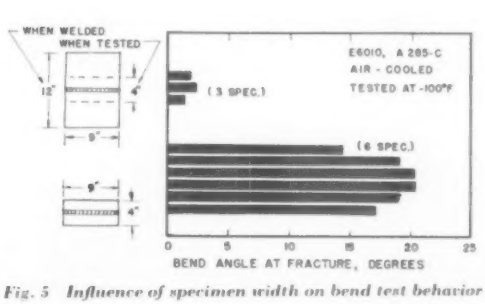


Fig. 5 Influence of specimen width on bend test behavior

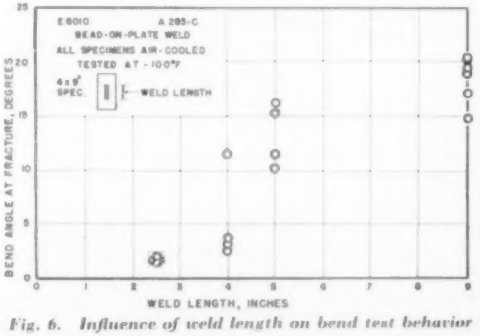


Fig. 6. Influence of weld length on bend test behavior

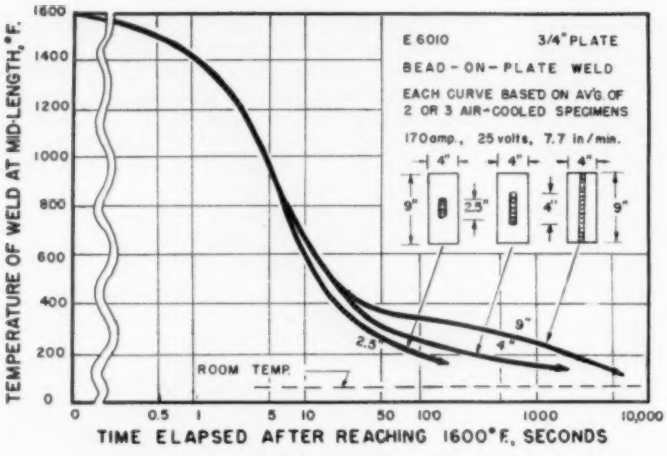


Fig. 7 Influence of weld length on the cooling rate of the weld

were deposited in the usual manner on standard 4- x 9-in. specimens. (See the sketch in Fig. 6). After welding, the specimens were cooled in air. Later they were notched and were tested at −100° F.

The results of the tests are shown in Fig. 6 where it will be seen that the values of bend angle at fracture decrease with decreasing weld length. The values for the $2^1/_2$- and 4-in. lengths are quite low.

The cooling curves for the $2^1/_2$-, 4-, and 9-in. welds (measured at mid length in each case) are shown in Fig. 7. At temperatures above 450° F. the curve for the 4-in. weld is indistinguishable from that for the standard 9-in. length. At lower temperatures the 4-in. weld cools more rapidly. It appears, therefore, that its inferior ductility must be attributed solely to the acceleration of low-temperature cooling.

Figure 7 indicates that the cooling of the $2^1/_2$-in. weld may be somewhat more rapid even at higher temperatures. It is thus conceivable that its brittleness is due in some degree to this factor as well as to the acceleration of low-temperature cooling.

7. SOME IMPLICATIONS

If one accepts the conclusion that weld ductility may be influenced by low-temperature cooling rates, it becomes necessary to recognize certain important implications of this influence. Some of them are suggested below.

A Limitation of Laboratory Data

It is evident that one should be wary of using the results of laboratory tests on small specimens to predict the ductility of welds deposited on large structures. Although the materials, the plate thickness and the welding conditions used in the laboratory may duplicate those employed in the large-scale work, differences in heat capacity may be expected to produce differences in low-temperature cooling rates and hence in capacities for plastic deformation. Perhaps in the past the importance of this point has sometimes been overlooked.

The Interpretation of Laboratory Results

The importance of considering low-temperature cooling rates in the interpretation of laboratory data may be suggested by means of an example. Let us suppose that an investigator interested in the transformation of austenite wishes to determine the effect of the cooling rate at 1000° F. on weld ductility. Many of the measures which might be taken to vary the cooling rate at this temperature also cause significant changes in the low-temperature range. If changes in ductility are noted, can they be attributed solely to the influence of the cooling rate at 1000° F? Additional tests would be needed to answer such a question.

Concerning Preheating

In welding practice, even in the case of mild steel, difficulty is sometimes encountered when work is welded at low temperatures and it is recognized that preheating at slightly elevated temperatures is effective in promoting ductility. That the initial temperature of the work should have such a great effect on ductility seems a bit difficult to explain in terms of its influence on high-temperature cooling alone. Perhaps much of the benefit can be attributed to the manner in which preheating influences low-temperature cooling. Moderate preheating retards cooling in the low-temperature range to a much greater extent than it affects the rates at higher temperatures.

8. TESTS ON LOW-HYDROGEN WELDS

Some of the observations described in the preceding sections suggest that the hydrogen content of the weld may be involved in the mechanism whereby ductility is influenced by low-temperature cooling. Such an influence has also been indicated in other investigations.[1, 2] For this reason, some of the tests of Section 4 were repeated on specimens welded with low-hydrogen electrodes of the E6016 type.

Prior to welding, the $^3/_{16}$-in. electrodes were baked out at 800° F. to minimize the hydrogen content of the coating. The welds were deposited at 20 v. with a current of 200 amp. and an arc speed of 7.4 in. per minute. As in Section 4, the specimens were allowed to cool in air for various periods after welding. They were then quenched in 70° F. water.

The results of the tests are shown in Fig. 8 where it

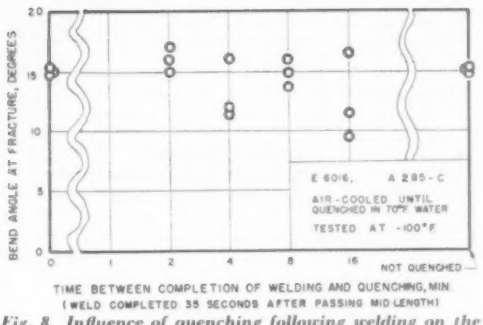

BEND ANGLE AT FRACTURE, DEGREES
E 6016, A 285-C
AIR-COOLED UNTIL QUENCHED IN 70°F WATER
TESTED AT -100°F
NOT QUENCHED
TIME BETWEEN COMPLETION OF WELDING AND QUENCHING, MIN.
(WELD COMPLETED 35 SECONDS AFTER PASSING MID-LENGTH)

Fig. 8 Influence of quenching following welding on the bend test behavior of E6016 welds

will be seen that the low-hydrogen welds were immune to embrittlement even when quenched immediately after the completion of welding. In additional tests the ductility of such welds was found to be unimpaired even when specimens were quenched in alcohol at −100° F. immediately after welding. It was noted also that air-cooled low-hydrogen welds were ductile under the conditions of Section 6, i.e., when deposited as welds of short length.

On the basis of these observations, there would seem little reason to doubt that the hydrogen content of the weld is important in the phenomenon of low-temperature cooling rate embrittlement.

9. ISOTHERMALLY TREATED SPECIMENS

Sections 4, 5 and 6 have shown that high ductility is promoted by the slow cooling of E6010 welds. It appears that, if only sufficient time is allowed, a change of a favorable nature occurs as the weld passes through the low-temperature range. Presumably, a decrease in hydrogen content or a redistribution of hydrogen is involved. This section is concerned with the manner in which the rate of this favorable change is influenced by temperature. It describes a series of tests in which, immediately after welding, specimens were held isothermally at 385, 280 and 212° F.

The treatments were conducted in constant-temperature oil baths of large volume. The specimens were welded in the usual fashion with E6010 electrodes. Within 7 sec. after the completion of welding they were placed in the oil baths where they were allowed to remain for periods ranging from one minute to several hours. Upon removal from the oil they were quenched in water at 70° F. Later they were notched and were tested in the usual manner.

The results of the tests are represented in Fig. 9 where, for each oil bath temperature, values of bend angle at fracture are plotted against time at temperature. It will be seen that the data for the three temperatures are rather similar and that they resemble the earlier data of Fig. 3. Low values of bend angle characterize the short holding times while larger values are produced by longer oil-bath exposures.

At holding times somewhat greater than 4 min. the data for each temperature indicate a rather pronounced change in ductility. It is surprising to find that the holding periods corresponding to these ductility transitions are so little dependent on the temperature of treatment. Whatever may be the exact nature of the hypothesized "favorable change," Fig. 9 suggests that it occurs nearly as rapidly at 212° F. as at 385° F. The rates of many metallurgical reactions, on the other hand, are known to vary a hundred-fold over such a range of temperature. In particular, this is true of the rate at which hydrogen escapes from welds.[1]

No effort was made to determine the rates at which specimens attained the desired temperatures after introduction into the oil baths. The oil was vigorously agitated to facilitate heat transfer but it is recognized that oil is not a highly efficient quenching medium. In this connection it is of interest to note the behavior of a group of specimens which were quenched in boiling water immediately after the completion of welding. The bend-test performance of these specimens is shown in Fig. 10. It will be seen that they fractured at low angles even after holding times of several hundred hours at 212° F. (Compare Fig. 10 with the 212° F. data of Fig. 9.) The dissimilar responses of the water-quenched and oil-quenched specimens are due presumably to the somewhat more rapid cooling of the former.

10. THE PERMANENCY OF EMBRITTLEMENT

This section is concerned with an interesting characteristic of E6010 specimens cooled too rapidly while still in a vulnerable condition following welding.

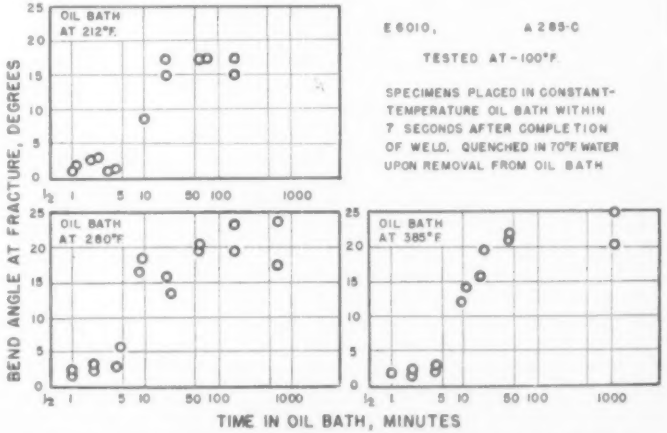

OIL BATH AT 212°F.
OIL BATH AT 280°F
OIL BATH AT 385°F
E 6010, A 285-C
TESTED AT -100°F
SPECIMENS PLACED IN CONSTANT-TEMPERATURE OIL BATH WITHIN 7 SECONDS AFTER COMPLETION OF WELD. QUENCHED IN 70°F WATER UPON REMOVAL FROM OIL BATH
BEND ANGLE AT FRACTURE, DEGREES
TIME IN OIL BATH, MINUTES

Fig. 9 Dependence of ductility on isothermal treatment in oil following welding

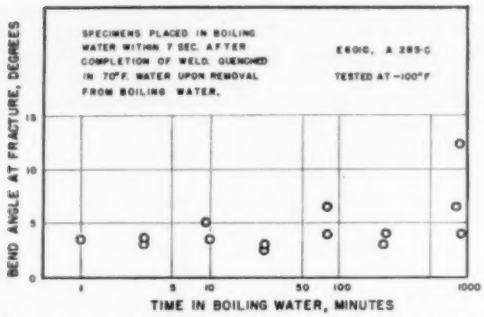

SPECIMENS PLACED IN BOILING WATER WITHIN 7 SEC. AFTER COMPLETION OF WELD. QUENCHED IN 70°F. WATER UPON REMOVAL FROM BOILING WATER.
E6010, A 285-C
TESTED AT -100°F
BEND ANGLE AT FRACTURE, DEGREES
TIME IN BOILING WATER, MINUTES

Fig. 10 Dependence of ductility on isothermal treatment in water following welding

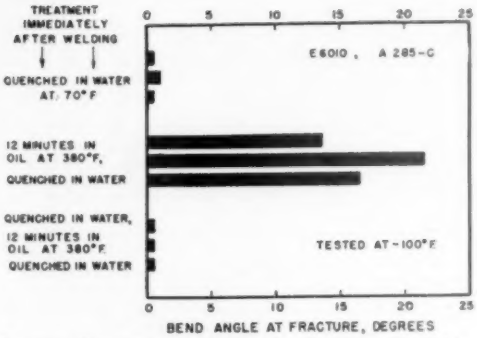

TREATMENT IMMEDIATELY AFTER WELDING
QUENCHED IN WATER AT 70°F
12 MINUTES IN OIL AT 380°F, QUENCHED IN WATER
QUENCHED IN WATER, 12 MINUTES IN OIL AT 380°F QUENCHED IN WATER
E6010, A 285-C
TESTED AT -100°F
BEND ANGLE AT FRACTURE, DEGREES

Fig. 11 The irreversibility of the effects of quenching following welding

A group of specimens was quenched in 70° F. water immediately after welding. According to Fig. 3 this treatment was expected to induce low ductility. A second group was held 12 min. at 380° F. following welding, after which it also was quenched. According to Fig. 9 these specimens were expected to show superior ductility. A third group, that under study, was quenched in 70° F. water immediately after welding. It was then reheated to 380° F. for 12 min. after which it was again quenched.

The subsequent bend-test behaviors of these specimens are shown in Fig. 11. The first and second groups, used as controls, behaved as anticipated. The third group broke at very low values of bend angle. Thus it appears that, whatever may be the nature of the damage caused by quenching immediately after welding, the process is not a reversible one. While the 380° F. treatment, applied before quenching, renders a specimen immune to subsequent damage, the same treatment is ineffective after quenching.

In subsequent tests it has been found that reheating, even at temperatures as high as 1150 and 1600° F., is incapable of restoring ductility. (In these tests, air cooling was employed following reheating.)

It should be emphasized at this point that the above references to permanency of damage apply only to specimens which were embrittled by the application of a 70° F. water quench directly after welding. No attempt has been made as yet to determine the permanency, if any, of the damage to specimens embrittled by less drastic treatments, such as by the air cooling of the wide specimens of Section 5. This latter question, one of obvious interest, is currently under investigation.

Other investigators have found evidence of microfissures in quenched E6010 and E6011 welds.[1,2] Such defects would of course account for a permanent loss in ductility. In the present investigation similar microfissures have been observed in specimens quenched immediately after welding and also in some of the brittle specimens subjected to less drastic cooling. (The specimens were sectioned and examined without bending.) It appears that fissures are present only in conditions of low ductility. These observations, as yet incomplete, will be reported in a later paper.

11. THE TESTING TEMPERATURE

It is believed that, under the conditions of the investigation, the fracture of the test specimen originates in the weld metal regardless of testing temperature (at least for values in the range from 70 to −100° F.). When tests are conducted at room temperature, however, the notch-resistance of the heat-affected zone and of the parent plate are ordinarily sufficient to resist the propagation of cracks so that the fracture of the entire specimen may occur at a bend angle much larger than that at which the weld has failed. To study the ductility of the weld itself, as was desired in this investigation, it is necessary either to observe the weld throughout the test or, as is in some ways more convenient, to render the material outside of the weld so notch-sensitive that it becomes unable to resist the propagation of cracks originating in the weld. Under the conditions of the paper, the latter aim may be accomplished by the use of a sufficiently low-testing temperature. It was for this reason that the tests were conducted at −100° F. Supplementary tests have shown that the bend angle values which correspond to the complete fracture of the weld itself are nearly independent of testing temperature in the range from 70 to −100° F.

The nature of the bend-test fracture is discussed in greater detail in reference 7.

Recently a number of bend tests and longitudinal tensile tests have been performed at room temperature to check the −100° F. indications reported in this paper. The principal tests of Sections 4, 8 and 10 have been repeated and in every case the earlier indications have been confirmed. This work, still in progress, will be reported in a later paper.

12. THE MECHANISM OF EMBRITTLEMENT

Although the mechanism of embrittlement is not entirely clear, some pertinent indications are furnished by the available evidence.

On the basis of Section 8 it seems certain that the hydrogen content of the weld plays an important role.

Confirming evidence has been reported by Bland. Such indications concerning the importance of hydrogen are not surprising since large hydrogen contents are imparted to the molten weld during deposition by E6010 electrodes and it is known that hydrogen is capable of embrittling steel. Furthermore, the elevated-temperature cooling which follows welding is so rapid that the opportunity for elevated-temperature diffusion is seriously restricted. Thus, considerable hydrogen may be retained as the weld approaches the low-temperature range. Slow cooling in the latter range would be expected to favor low-temperature diffusion. In an earlier investigation employing specimens somewhat similar to those of the present study it was found that air-cooling produced a hydrogen content of about 4 cc. per 100 grams of weld metal while specimens quenched following the completion of welding exhibited a content of about 15 cc. per 100 grams.[1]

That the role of hydrogen is not a simple one is suggested by earlier work on preheated welds. In reference 1 it is reported that preheating at temperatures up to 375° F. caused increases in the hydrogen content of air-cooled welds while at the same time enhancing ductility. (The increased hydrogen content was thought to originate in greater pickup before solidification.) This would seem to indicate that it is not the total hydrogen content alone which is decisive. Perhaps the distribution of whatever hydrogen may be present is of greater significance.

Another puzzling aspect concerning the role of hydrogen has already been cited in Section 9 where it was found that the response of welds to isothermal treatment was about the same at 212° F. as at 385° F. Diffusion of hydrogen would be expected to be a hundred-fold faster at the higher temperature.

Rapid cooling, in addition to impeding the diffusion of hydrogen, may also be expected to maximize the thermal stresses which affect the weld during cooling. Sufficiently severe stresses in the presence of hydrogen embrittlement might promote fissuring. Perhaps the "permanent" damage of Section 10 can be explained on this basis. The importance of quenching stresses is also suggested by the dissimilar behaviors of specimens quenched in oil at 212° F. and in boiling water (section 9).

Concerning the role of stress, it should be remembered that even in an air-cooled specimen, residual stresses normally approach a value of 60,000 psi. in the weld.[1]

For a better understanding of the mechanism of embrittlement, it appears that further work is necessary. It is conceivable that factors other than hydrogen and stress must be taken into account. Perhaps austenite is retained in significant amounts in mild-steel welds.[6] If such is the case, the retained austenite might act in conjunction with hydrogen. There is the further possibility that the mechanism may involve precipitation of nitrides or carbides in the low-temperature range. It seems not improbable that the phenomena described in this paper are related to the better-known effects of preheating and postheating. Perhaps they are in some way related to the occurrence of strain aging in welds.[7] Work now in progress is designed to illuminate these possibilities.

13. SUMMARY AND CONCLUSIONS

To determine the importance of low-temperature cooling rates following welding, several methods were employed to vary these rates while holding other factors fixed. The measures included direct quenching following welding, the air-cooling of wide specimens, the air-cooling of short welds and several isothermal treatments. Ductility was measured by means of a bead-on-plate longitudinal notched-bend test at −100° F. The cooling rates of the welds were determined by means of thermocouples which were introduced into the molten metal during welding. The principal results and conclusions may be summarized as follows.

1. Low ductility is produced by the rapid cooling of E6010 welds at low temperatures following welding. It appears that cooling rates may be important at temperatures at least as low as 212° F.

2. The ratio of the total heat capacity of the work to the heat input in welding strongly influences low-temperature cooling rates although it ordinarily has a negligible effect on the rates at higher temperatures.

3. By tripling the width of a typical laboratory specimen (thus obtaining a three-fold increase in heat capacity), low ductility was produced even in air-cooled welds.

4. On the basis of item 3, it is suggested that the ductility of welds on large structures may often be inferior to that of small laboratory specimens which, aside from their smaller heat capacity, are produced under identical conditions. It would appear that caution should be observed in using the results of laboratory tests to predict the behavior of welds on large structures.

5. It is suggested that some of the benefits of preheating, especially in the case of mild steel, can be attributed to the retarding of low-temperature cooling.

6. Welds produced with low-hydrogen electrodes have been found to be immune to embrittlement by rapid cooling at low temperatures.

7. Although it is evident that the hydrogen content of the weld plays an important role, the mechanism of embrittlement is not fully understood. The present evidence does not exclude the possibility that other factors, such as the retention of austenite or the precipitation of nitrides or carbides, may also be involved. Nor is the role of thermal stress clear.

8. In most respects, the present results are in good qualitative agreement with those published by Bland.

References

1. Flanigan, A. E., "An Investigation of the Influence of Hydrogen on the Ductility of Arc Welds in Mild Steels," The Welding Journal, **26** (4), Research Suppl., 193-s to 214-s (1947).

2. Bland, J., "Effect of 'Quench Time' on Weld Metal," *Ibid.*, **28** (5), Research Suppl., 216-s to 226-s (1949).

3. Bocarsky, S. I., "The Effect on Ductility of Accelerated Cooling of Mild-Steel Welds at Temperatures Below 600° F.," Senior Thesis, School of Engineering, University of California, Los Angeles, Fall 1948.
4. Bocarsky, S. I., "The Effects on Ductility of Varying the Cooling History below 600° F. of Mild-Steel Welds Made with E6010 Electrodes," Senior Thesis, School of Engineering, University of California, Los Angeles, Spring 1949.
5. McGuire, G. B., "The Influence of Low-Temperature Cooling Rates Following Welding on the Ductility of Arc Welds in Mild Steel," Senior Thesis, School of Engineering, University of California, Los Angeles, Summer 1949.
6. Averbach, B. L., Castleman, L. S., and Cohen, M., "Measurement of Retained Austenite in Carbon Steels," *Trans. A.S.M.*, **42**, 112–129 (1950).
7. Flanigan, A. E., Kaufman, M., and Emery, E. M., "Strain-aging of Arc Welds in Mild Steel," The Welding Journal, **29** (3), Research Suppl., 146-s to 160-s (1950).

Comparative Tests of Different Types of Notch Impact Specimens*

The transition temperature t_1, Fig. 1, of a killed basic open-hearth steel was measured with three types of specimen, each 0.394 in. square, $2^3/_{16}$ in. long. Type 1 specimen had a notch 0.20 in. deep, 0.04 in. radius and is the specimen recommended by the International Standards Assn. Type 2 specimen had a notch 0.12 in. deep, 0.04 in. radius and is the standard German DVMR type. In Type 3 specimen the notch depth was 0.08 in., the notch radius being again 0.04 in. This is the Mesnager specimen used in Belgium.

The steel used in the investigation was normalized after rolling at the Royal Netherlands Blast Furnace and Steel Co. A tensile specimen (cross section = $1^3/_{16} \times {}^5/_8$ in.) had an ultimate strength of 64,000 psi. with an elongation in 8 in. of 28.1%. The steel analyzed 0.13% carbon, 0.94% manganese, 0.28% silicon, 0.009% phosphorus and 0.032% sulphur. The notch impact specimens were cut from the middle of the plate, Fig. 2.

The results are plotted in Fig. 3. For types 1 and 2 the transition temperature lay between −20 and −40° C. The Mesnager specimen, on the other hand, indicated a transition temperature below −60° C.

* Abstract of Research Report No. 3 of the Netherlands Welding Society. The Report is entitled "Vergelijkende Proeven met Kerflagstaven van Verschillend Type," published in Lastechniek, 16, p. 79–81, May 1950. (Abstracted by Dr. G. E. Claussen.)

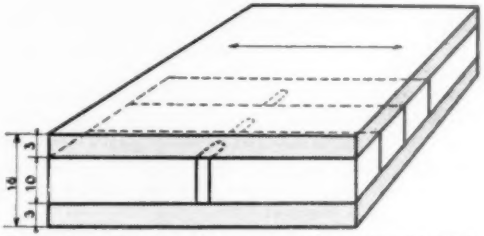


Fig. 2 Location of notch impact specimens in mid-thickness of ${}^5/_8$ in. plate

Arrow shows direction of rolling. Dimensions in millimeters

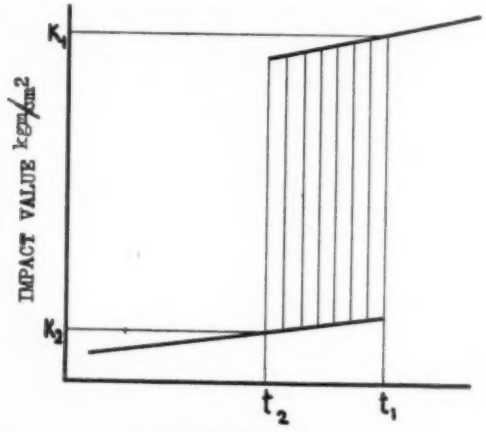


Fig. 1 Schematic diagram of impact value vs. test temperature. t_1 = transition temperature

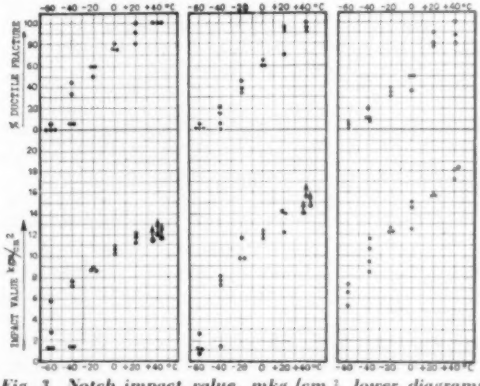


Fig. 3 Notch impact value, mkg./cm.², lower diagrams and per cent ductile fracture, upper diagrams

Left hand diagrams—type 1 specimen, notch 0.20 in. deep; middle diagrams—type 2 specimen, notch 0.12 in. deep and right hand diagrams—type 3 specimen, notch 0.08 in. deep

The Micro-Mechanism of Fracture in the Tension-Impact Test

This report gives the results of metallographic studies which were made on a number of specimens of rimmed, semikilled and fully killed steels and of Armco Iron which were partially fractured, or loaded just to fracture, then sectioned and examined

by W. H. Bruckner

INTRODUCTION

A LARGE number of Type B, notched specimens of steels have been tested in axial tension impact and the curves relating impact energy and per cent reduction of area to the testing temperature have been obtained.[1] In general it has been found that rimmed steels have a relatively higher transition temperature than do the better grades of semikilled or fully killed steels. It was found that steels whicl had a high transition temperature in the wide-plate investigation[2] showed little or no change in the transition temperature when the initial energy of the tension-impact test was varied from 220 and 110 to 45-ft.-lb.

The impact testing program has contributed to the available information on the relative sensitivity of different steels to brittle failure. However, a more fundamental significance could be given to studies of the essential differences in fracture behavior between sensitive and relatively insensitive steels. Such a course of study was initially visualized as a metallographic survey of specimens which had been fractured in determining the curves of impact energy vs. temperature. Postmortem metallographic studies were found to be unsatisfactory since it was not possible to separate out from the whole fracture history any differences in the sequence of failure which was characteristic of any one steel or of different temperatures of test.

An exploration was made of the possibility of partially fracturing the specimens and subsequently sectioning them for metallographic studies. It was found that the impact energy-temperature curve for an initial energy of 45 ft.-lb. could serve as a guide for an impact loading schedule which would furnish specimens partially fractured at any desired energy level. To illustrate, assume that the impact-temperature curve for 45 ft.-lb. initial energy shows an average of 450 ft.-lb./in.^{2} energy absorption for fracture at 20° F. An initial energy of the pendulum somewhat greater than that equivalent to energy absorption of 450 ft.-lb./in.^{2} was found to be necessary for fracture because of the elastic energy required for fracture but not measured during the impact test. On sectioning specimens which were loaded in impact but not fractured (say at 20° F. at a value of 450 ft.-lb./in.^{2} or less) it was found that an internal crack system was developed and the extent of cracking could be varied by varying the impact load.

Any steel for which the impact-temperature curve was available for 45 ft.-lb. initial energy could be scheduled for partial fracture at any temperature below, in or above the transition range. The sequence of fracture in any part of the impact energy-temperature curve was thus provided in subsequent microexamination by having the fracture occur in steps. The micromechanism of the fracture could be reconstructed from the stepwise progression of the fracture. This report gives the results of metallographic studies which were made on a number of specimens of rimmed, semikilled and fully killed steels and of Armco Iron which were partially fractured, or loaded just to fracture, then sectioned and examined.

MATERIALS

The chemical analyses of the structural steels which are the subject of the present report are given in Table 1. The steels which are marked with an asterisk are the project steels which have been used for previous wide plate and impact investigations referred to in the footnotes. The nonproject steels were not used in the wide plate investigations but were reported as tested in axial tension impact.[1] All of these steels were available as hot-rolled $^3/_4$-in. thick plate with the exception of Steel *Dn* which was normalized at the mill and the Armco iron which was furnished as $^5/_8$-in. round, cold-rolled bar stock.

METHODS OF PROCEDURE

Cylindrically notched specimens of the type identi-

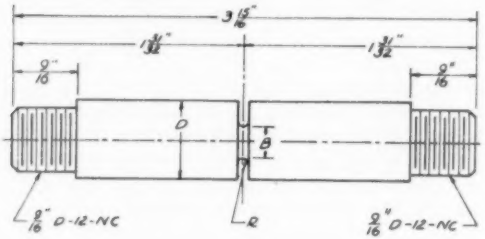
W. H. Bruckner is Research Associate Professor of Metallurgical Engineering, University of Illinois, Urbana, Ill.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

Table 1—Chemical Analyses of Steels

Steel*	Kind of steel	Treatment	Per cent by weight of element noted											
			C	*Ma*	*P*	*S*	*Si*	*Al*	*Ni*	*Cu*	*Cr*	*Mo*	*Si*	N_2
A*	Semikilled	As-rolled	0.26	0.50	0.012	0.039	0.03	0.012	0.02	0.03	0.03	0.006	0.003	0.004
C*	Semikilled	As-rolled	0.24	0.48	0.012	0.026	0.05	0.016	0.02	0.03	0.03	0.005	0.003	0.009
Dr*	Killed	As-rolled	0.22	0.55	0.013	0.024	0.21	0.020	0.16	0.22	0.12	0.022	0.023	0.006
Dn*	Killed	Mill normalized	0.19	0.54	0.011	0.024	0.19	0.019	0.15	0.22	0.12	0.021	0.025	0.006
RR	Rimmed	As-rolled	0.27	0.33	0.008	0.025	0.01	...	..	..	..	...	...	0.006
RK	Killed	As-rolled	0.23	0.47	0.008	0.029	0.16	...	..	..	..	...	...	0.008
Armco Iron†	Received as normalized and stress relieved at 1100° F.	cold rolled, at 1700° F.	0.02	0.01	0.004	0.025	..	..	..	0.12	..	...	...	...

* This mark indicates the material as a project steel used for wide plate tests.
† Mill analysis of Armco Iron.



B	D	R
0.294	0.625	0.039

Fig. 1 Design of type B notched, tension-impact specimen

fied as standard, Type B in Fig. 1 were machined from the 3/4-in. thick steel plates, with the length of the specimen in the rolling direction. The curves of the impact energy and of per cent reduction of area vs. testing temperature for an initial energy of 45 ft.-lb. are reproduced in Fig. 2 from previously published data. These data had been established earlier with standard Type B specimens.

It was intended to obtain for each steel a series of specimens partially fractured above the transition temperature in the transition temperature range and below the transition temperature as given by the curves shown in Figs. 2 (*A*) and 2 (*B*). The variation in initial energy of the pendulum which was required to produce partial fractures of varying degree was obtained by lifting the pendulum with attached specimen up to different heights before release of the pendulum for the impact load. This variation in initial energy was obtained by means of a modification of the Riehle impact tester as shown in Fig. 3. It should be noted that both initial energy and pendulum velocity were varied by such procedure but the change in velocity accompanying a change in initial energy was only about one-half as great.

When used for the tension-impact test the pendulum of the Riehle machine is calibrated to swing to zero energy absorption when the screw fixture and one-half of a fractured impact specimen are attached to the pendulum. For each pendulum height corresponding to a certain, chosen initial energy the height was adjusted to have the scale pointer swing through an arc corresponding to the chosen initial energy value when the screw fixture and one-half of a broken specimen were attached to the pendulum. When fracture occurs the tup and one-half of the attached specimen break away

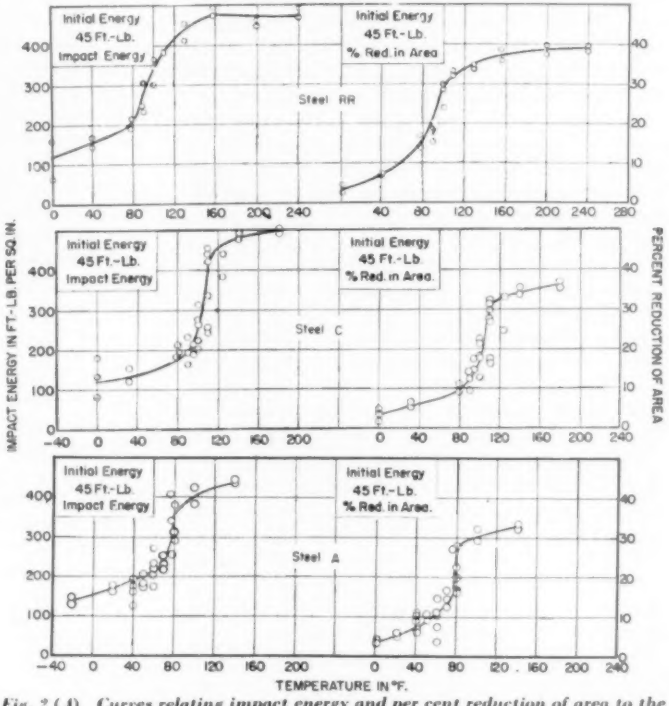

Initial Energy 45 Ft.-Lb. Impact Energy
Initial Energy 45 Ft.-Lb. % Red. in Area
Steel RR
Steel C
Steel A
IMPACT ENERGY IN FT.-LB. PER SQ. IN.
PERCENT REDUCTION OF AREA
TEMPERATURE IN °F.

Fig. 2 (A) Curves relating impact energy and per cent reduction of area to the temperature of the impact test for an initial energy of 45 ft.-lb. Steels RR, C and A

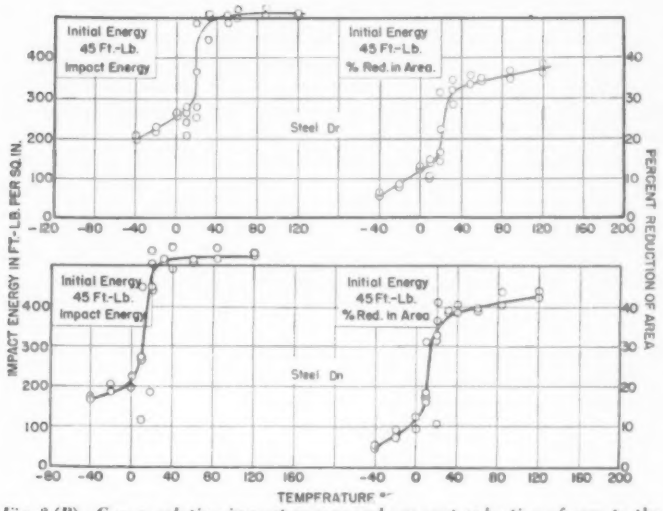


Fig. 2 (B) Curves relating impact energy and per cent reduction of area to the temperature of the impact test for an initial energy of 45 ft.-lb. Steels Dr and Dn

from the pendulum. The initial energy which the tup and one-half specimen represent are thereby removed from consideration in determining the energy absorbed in the fracture. When the specimen does not fracture completely the whole pendulum rebounds and swings back toward the initial starting position, therefore, the amount of energy absorbed by the specimen cannot be measured by means of the scale on the impact testing machine. Some thought was given to the possibility of measuring the angle of rebound and thereby determining the elastic energy absorbed by the specimen and returned to the pendulum. It was considered that the arc of rebound could also be related to the plastic energy absorbed by the specimen. However, in the actual procedure it was found difficult to do more than catch the pendulum upon rebound and to prevent by this means the application of more than one impact blow. It was also determined later in the program that the energy absorbed in partial fracture could be determined approximately by other means, i.e., from the energy-per cent reduction of area relationship which is a straight line. The data for previous tests at 45 ft.-lb. initial energy were used to establish the straight-line relationship for each steel.

The specimens which were loaded in impact to obtain partial or complete fracture were sectioned as shown in Fig. 4 to obtain a plane of

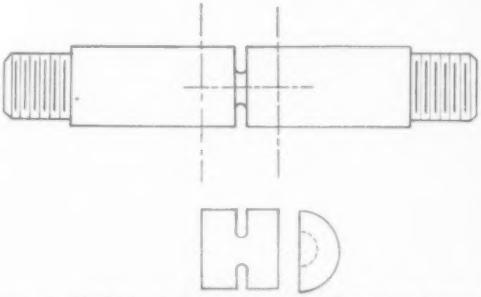


Fig. 4 Method of sectioning notched tension-impact specimen for metallographic examination

metallographic examination parallel with the maximum principal stress in impact. This plane was also chosen to represent the longitudinal plane through the center of the volume of metal under the notch. This plane was the same plane that the center line of the pendulum traverses during the impact test.

The specimen sections were mounted in bakelite and were processed to obtain surfaces suitable for metallographic examination. Surveys of the entire area in the notch region were then made in the unetched condition and after etching with 5% Nital solution. Results of the examination were recorded as notes on observations and by photographic means. The notes indicated which features of the microstructure were characteristic of certain specimens, and photomicrographs were made to record these characteristic features.

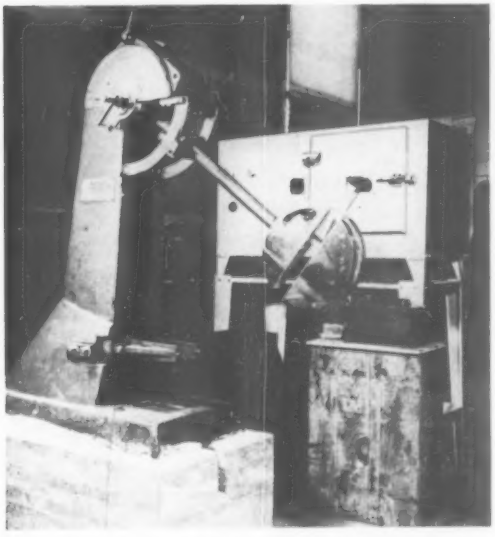


Fig. 3 Riehle impact-testing machine with modification for tests at initial energy below 110 ft.-lb.

DATA OBTAINED AND DISCUSSION OF DATA

Table 2 summarizes the results of axial tension-impact tests made to establish a series of specimens loaded in impact just to fracture and a series of specimens loaded

less than required for complete separation. The table shows the energy absorbed for fracture which was measured on the impact testing machine. The estimated energy absorption of specimens which did not fracture is given in parentheses in Table 2. These estimated values were obtained from the curves determined previously for the relationship between energy absorbed and reduction of area for specimens broken in impact with 45 ft.-lb. initial energy. Since the reduction of area was determined for specimens which fractured and for those which did not fracture, the average energy absorption corresponding to any value of per cent reduction of area could be determined approximately from the previously obtained curves of energy absorption vs. per cent reduction of area. In Table 2 there is shown to be a fair correspondence between the measured energy absorption and the estimated energy absorption for specimens which were fractured during the tests.

The specimens listed in Table 2 which were loaded in impact were all sectioned for metallographic examination except specimens M92 and M94.

In the last column of Table 2, under remarks, are given the results of metallographic examination of the polished, and the polished and etched specimens prepared as described under procedures. In the tensile-

Table 2—Results of Tension Impact Loading Schedule for Different Steels

Spec. No.	*Testing temp., °F.*	*Initial energy, ft.-lb.*	*Energy absorbed ft.-lb.**	*Energy absorbed ft.-lb./in.²†*	*Reduction of area, %*	*Observation notes on microstructure‡*
I. Steel RR; rimmed, as-rolled transition temperature 100° F.						
M-48	95	17.9	..	(204)	12.5	F. P. and T
M-59	95	19.8	..	(227)	14.4	F. P., shear regions
M-30	95	20.7	..	(263)	17.5	F. P., shear regions and T
M-70	95	22.1	..	(267)	18.1	F. P., shear region
M-92	95	24.1	..	(309)	21.8	Not examined
M-65	95	24.2	..	(305)	21.2	F. P., shear regions
M-94	95	26.3	24.9	370 (345)	24.8	Not examined
M-28	78	10.0	..	....	7.0	F. P., cracks at ferrite grain boundaries
M-101	78	14.0	..	....	10.0	F. P., twins outside of notch area
II. Steel C; semikilled, as-rolled transition temperature 110° F.						
E-36C	100	30.0	..	(337)	22.4	F. P., cracks at ferrite grain boundaries
E-45C	100	33.2	29.6	440 (439)	30.6	F. P., cracks at ferrite grain boundaries
E-43C	40	11.7	..	(126)	5.4	F. P.
E-31C	40	12.6	..	(133)	6.1	Ferrite grain boundary cracks
E-35C	40	13.8	..	(138)	6.4	F. P., ferrite grain boundary cracks
E-41C	40	14.8	10.8	159 (150)	7.4	Twins and cleavage
E-34C	40	18.9	11.6	172 (147)	7.3	F. P. and cleavage cracks
III. Steel A, semikilled, as-rolled transition temperature 80° F.						
F-40-A	77	14.0	..	(175)	8.0	One twin
F-45-A	77	21.8	..	(263)	16.3	F. P., ferrite boundary cracks
F-34A	77	25.6	..	(306)	20.6	F. P., ferrite boundary cracks
F-50A	77	27.1	..	(343)	24.0	F. P., ferrite boundary cracks
F-30A	77	29.0	22.4	324 (326)	22.4	F. P., twins and cleavage
F-49A	77	30.7	27.5	391 (428)	32.3	F. P., ferrite boundary cracks
F-44A	20	13.0	..	(139)	4.7	F. P. near notch, one crack
F-38A	20	13.8	..	(160)	6.7	F. P., T and ferrite boundary cracks
F-43A	20	14.3	..	(169)	6.8	F. P. and cleavage cracks
F-31A	20	14.7	11.8	177 (183)	8.7	F. P., T and cleavage cracks
F-39A	20	20.5	12.3	181 (173)	8.0	F. P., T and cleavage cracks
IV. Steel Dr; killed as-rolled transition temperature 20° F.						
K-29	79	16.0	..	(230)	9.6	No change apparent
K-46	79	20.0	..	(260)	12.3	F. P.
K-49	79	28.5	..	(355)	20.8	F. P.
K-43	79	39.0	36.5	542 (530)	36.8	F. P., general flow of ferrite
K-41	20	28.5	..	(340)	19.2	No change apparent
K-35	20	32.0	..	(485)	21.1	F. P.
K-37	−20	14.0	..	(190)	5.8	No change apparent
K-34	−20	15.9	..	(300)	7.0	F. P.
K-39	−20	18.0	..	(325)	8.8	T in grain boundaries, internal holes
V. Steel Dn, killed, normalized transition temperature 15° F.						
G-82	20	27.2	..	(334)	21.9	No change apparent
G-88	20	29.3	..	(346)	23.0	F. P. near notch
G-81	20	31.2	..	(377)	26.2	F. P., twin in ferrite boundaries, cleavage
G-96	20	32.6	..	(387)	27.0	F. P., twin in ferrite boundaries, cleavage
G-80	20	33.7	27.3	408 (367)	25.2	F. P., cleavage, broad twins
VI. Armco Iron, normalized and stress-relieved transition temperature 80° F.						
2AN1	78	6.9	..	(99)	7.9	T in several grains
4N3	78	8.5	..	(106)	8.7	T in region on both sides of notch
4N4	78	10.3	..	(108)	9.3	T in bands at edge of notch area
4AN3	78	10.4	..	(137)	13.3	T and ferrite boundary cracks
4AN1	78	11.9	..	(121)	12.2	T and flow in ferrite
7AN5	76	12.0	8.1	137 (141)	14.1	T in fracture region

NOTES: The transition temperatures given are for an initial energy of 45 ft.-lb.
* The energy for complete fracture.
† Estimated energy shown inside ( ).
‡ F. P. signifies fractured pearlite, "T" signifies mechanical twins.

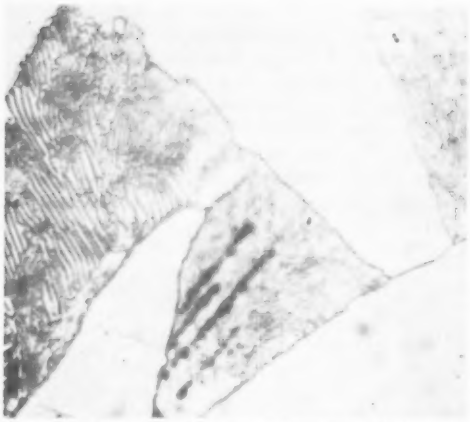


Fig. 5 Pearlite microfracture in specimen F34A, tested at 77° F. with 25.6 ft.-lb. initial energy. Etchant 5% nital, magnification 2000 ×

impact test the metallographic examination and the recording of microstructures can be carried out with the specimen so oriented that the direction of the principal stress is known. All of the micrographs which are given in the figures illustrating this report with the exception only of Fig. 17 are so oriented that the maximum principal stress is in the vertical direction on the page, i.e., from top to bottom. The metallographic studies show that the first manifestation of fracture in the transition region is the appearance of microfractured regions across the lamellae of pearlite grains. Observation of a large number of such pearlite fractures in various impact specimens indicated that the lamellae in which fracture was observed have a definite range of orientation of 45° or less with respect to the maximum principal, axial stress of the impact test.

Figures 5 and 6 show, respectively, for specimens F34A and F50A, regions of pearlite fracture which are illustrated at a magnification of 2000 ×. The specimens were loaded in impact as shown in Table 2 to

Fig. 6 Pearlite microfracture in specimen F50A, tested at 77° F. with 27.1 ft.-lb. initial energy. Etchant 5% nital, magnification 2000 ×

give partial fractures at 77° F. The pearlite lamellae in which fracture occurred, as illustrated in both figures, are shown to be oriented almost parallel with the direction of the principal stress, i.e., at least the traces of the pearlite plates on the polishing plane have this orientation. The traces of the fracture planes in Fig. 5 for both pearlite grains make an angle of approximately 41° with the maximum principal stress. For Fig. 6 this same angle appears to be approximately 50 to 52° for both pearlite grains which were fractured.

It appeared to be desirable to obtain irrefutable evidence of the existence of fracture in the pearlite by recording the fracture areas of unetched specimens of a number of steels. Accordingly, Fig. 7 is for the unetched specimen and shows clearly at a magnification of 2000 × that the pearlite fractures typical of those shown in the etched microstructures of Figs. 5 and 6 are in fact microfractures. A carbide etch was employed to determine the locus of the incomplete frac-

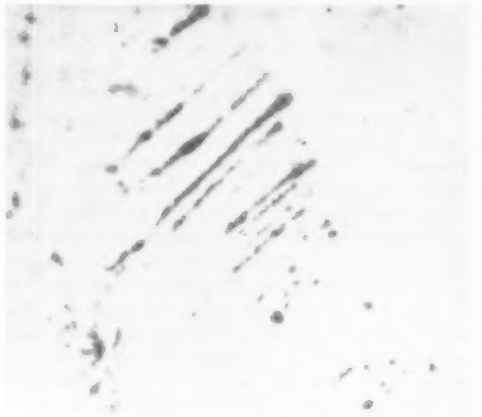


Fig. 7 Microfracture of carbide lamellae of pearlite in specimen F50A. Unetched, magnification 2000 ×

tures shown as black dots or serrations in the lower edge of the fracture region of Fig. 7. The fracture portions of the incomplete fractures were found to be the carbide lamellae of the pearlite grains. The progress of fracture across the pearlite therefore appears to be fracture in one or more of the carbide lamellae and linking up of these fractures by propagation through the ferrite lamellae until the fracture has traversed a portion or the whole of the pearlite grain. It can be noted that the trace of the plane of fracture shown in Fig. 7 was measured and found to be disposed to the maximum principal stress at an angle of 46°.

Microfractures were also observed at ferrite grain boundaries which were partially outlined by a carbide envelope. In many cases the carbide envelope appeared to be an extension of a single carbide lamella from a neighboring pearlite area. Two examples of this boundary fracture are given in Figs. 8 and 9, respectively, for Spec. F50A and Spec. F38A which are, respectively, at a magnification of 2000 × and 4000 ×.

For the rimmed Steel *RR* the sequence of fracture in

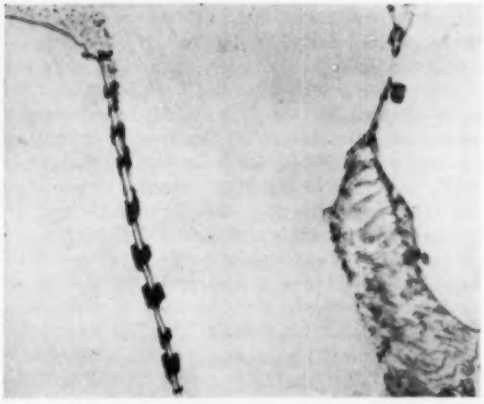


Fig. 8 Microfracture of carbide at ferrite grain boundary of specimen F50A. Etchant 5% nital, magnification 2000 ×

the transition region is characterized by generation of localized regions of intensive shear deformation of the ferrite. Such a region is shown in Fig. 10 at a magnification of 1500 × for Spec. M-65. The shear region is oriented at 52° to the maximum principal stress and is one of several typical regions found in this specimen. Figures 11 and 12 are shear regions in other specimens of rimmed steel which have developed fractures in the deformed ferrite and in several pearlite areas. The ferrite fractures appear to involve grain boundaries and the production of highly distorted regions within the ferrite grains. The shear areas appear to propagate through the notch volume of the specimen by advancing the ends of the lens-shaped region and joining up with similar areas. The shear areas in the specimens examined have an average length of about 0.01 mm. and a maximum thickness of about 0.002 to 0.003 mm. as determined from their traces on the polishing plane.

A considerable effort was made to develop a method of producing etch pits with which orientation of the ferrite grains could be determined. It was desirable to obtain etch pits which were of small size, sharp in outline, and without obscuring the important features of the microstructure of a fractured or partially fractured specimen. By ordinary methods for producing etch pits with 4% aqueous HNO_3 as described in the literature the microstructure is so severely attacked as to be practically unrecognizable. A method was developed which combined electrolytic activation in dilute HNO_3 and a short period of etching in 2% aqueous HNO_3.

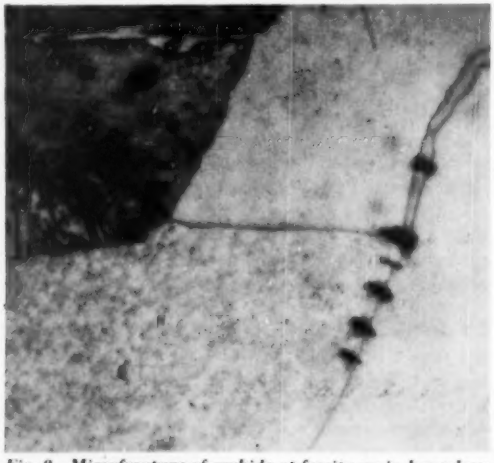


Fig. 9 Microfracture of carbide at ferrite grain boundary of specimen F38A. Etchant 5% nital, magnification 4000 × (Reduced 1/4 in reproduction)

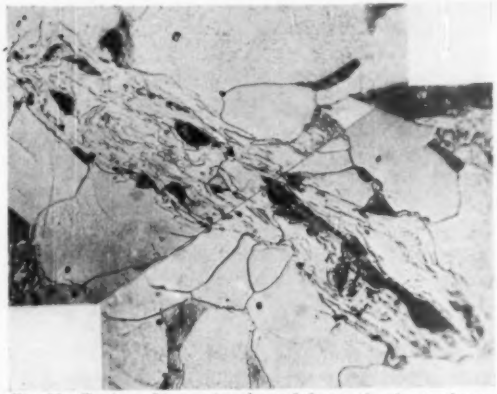


Fig. 10 Region of intensive shear deformation in specimen M-65 tested at 95° F. with initial energy of 24.2 ft.-lb. Etchant 5% nital, magnification 1500 × (Reduced 1/2 in reproduction)

Fig. 11 Region of shear deformation in specimen M-70 tested at 95° F. with 22.1 ft.-lb. initial energy. Etchant 5% nital, magnification 1500 × (Reduced 1/2 in reproduction)

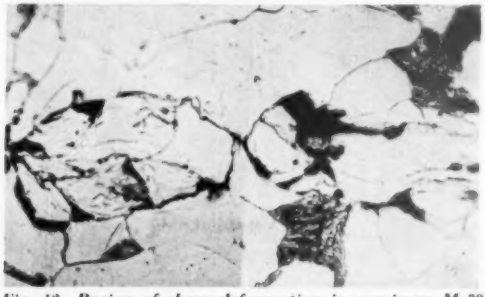
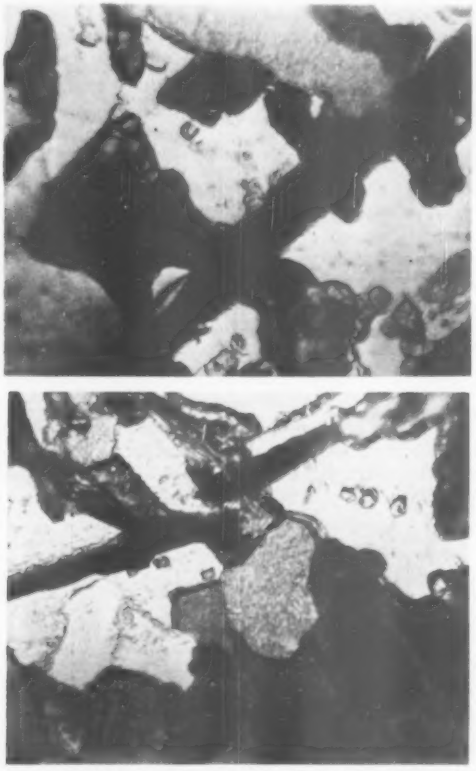


Fig. 12 Region of shear deformation in specimen M-30 tested at 95° F. with 20.7 ft.-lb. initial energy. Etchant 5% nital, magnification 1500 × (Reduced 1/2 in reproduction)

This procedure gave small, well-developed etch pits without destruction of the microstructure. Examples of the product are given in Figs. 13 and 14 which show the etch pits in relation to the internal cracks produced in Spec. E34C during impact testing. The straight sides of the etch pits give the orientation of the 100 lattice planes or cube faces of the unit cell in the ferrite grains. The cracks in the specimen are shown to be parallel with the sides of the etch pits in any one ferrite grain thus providing proof that the fracture is occasioned by cleavage which takes place along the 100 planes in alpha iron. In Figs. 13 and 14 the pearlite areas are seen to be much more severely attacked by etching than are the ferrite grains, and the cleavage cracks are appreciably widened.

For the same specimen E34C in which the etch pit method was later applied, as shown in Figs. 13 and 14, a record was made (prior to the etching for etch pits) of partial failure in a region near the actual failure. This is shown in a series of fractures in Figs. 15 at 2000×. Here are shown the fractures in the pearlite regions and the fractures in a carbide extension at the ferrite grain boundary. Another system of fractures appears to involve only the ferrite grains. The fractures in the pearlite make an angle of about 33° and



Figs. 13 and 14 Specimen E34C etch-pitted to show relation of etch pits and cleavage cracks. Etchant 2% aqueous HNO_3, magnification 1500 × (Reduced 1/3 in reproduction)

Fig. 15 Microfracture in pearlite and cleavage fractures in ferrite of specimen E34C. Etchant 5% nital, magnification 2000 ×

the pearlite lamellae an angle of about 21° with the maximum principal stress. The fractures in the ferrite are disposed at an angle of about 63° to the maximum principal stress. It was especially noted in this micrograph that the regions of fracture in the carbide envelope of the ferrite grain, at the center of Fig. 15, had a characteristic etching pattern in the ferrite grains bordering the fractured carbide.

The etching pattern reveals the formation of etch pits in the ferrite at the point of fracture in the carbide. This etch-pit pattern is also shown for the ferrite grains to the left of and bordering the large pearlite grain and for a boundary carbide of a ferrite grain directly beneath the large pearlite grain. These etch-pit patterns were not formed by the specially developed etching procedure for etch pits but they were formed by the 5% Nital etchant which is normally used as a general etchant to reveal ferrite grain boundaries and carbides. The reason these etch pit patterns develop would appear to be the same as for the formation of etch pits. In the usual procedure for developing etch pits the rapid attack of the etching solution causes localized gradients in the chemical reactivity which is considered to be responsible for etch pit formation.[3] In Fig. 15 it can be noted that in the center the carbide envelope has been fractured or bent at several points and the rectangular areas characteristic of etch pits are formed by the etchant in these regions. It is postulated that the microcracks have produced such highly localized strain that a high level of chemical reactivity is established locally in applying a general etching procedure. This tendency to form etch pits in regions of high localized strain is also shown in Fig. 8.

The etch pit areas in the ferrite near the microcracks which are shown in Fig. 15 are oriented so as to make

Fig. 16 Mechanical twins and cleavage crack in ferrite of specimen E41C. Etchant 5% nital, magnification 1000 ×

one side of the pits parallel with the cracks which traverse most of the ferrite grains in the field. The cracks are therefore cleavage cracks generated by the carbide microcracks. The orientation of the etch pit with respect to the microcracks, e.g., the diagonal of the etch pit is parallel with the microcracks, suggests that the ferrite has attempted to twin mechanically as an intermediate step before cleavage occurs. Figure 16 shows a region in Spec. E41C in which a cleavage crack was apparently initiated by the mechanical twins. The traces of the twins on the polishing plane make an angle of 58 to 59° with each other. The dark line which is later identified as a cleavage crack and which is shown as originating from the vertex of the angle formed by two twins makes an angle of 27 to 31° with the twin on either side, thus indicating the polishing plane to be very close to a 100 lattice plane. The crack is therefore seen to almost bisect the angular region between a set of twins, furthermore the crack is shown to be parallel to one side and normal to another side of the corner of a partially developed etch pit in the center of the field. The crack is therefore a cleavage fracture. It is not possible from Fig. 16 to determine whether the mechanical twinning preceded or followed the cleavage fracture. Fortunately several years ago while having a brittle, service fracture under observation it was noted that one ferrite grain had a set of three mechanical twins with a cleavage fracture traversing the ferrite grain

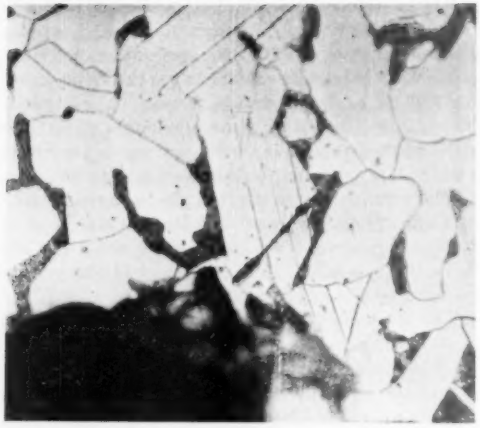


Fig. 17 Mechanical twins and cleavage crack in a single ferrite grain of service fracture. Etchant 5% nital, magnification 500 ×

in such a manner as to fracture all three twins as shown in Fig. 17. It can be noted that the twins are translated across the cleavage crack thus indicating that the cleavage fracture occurred after the twins had been formed. It should also be noted that Fig. 17 is not oriented on the page in any particular manner with respect to the principal stress as are all the other micrographs in this report, since for the service fracture the stress directions were not given. Additional evidence of twin-initiated cleavage is given for the studies of Armco iron.

TENSION-IMPACT TESTS OF ARMCO IRON

Tension-impact tests were made on Armco iron to determine the mode of fracture in the absence of carbides. This objective was not quite realized due to the 0.02% carbon content of the Armco iron but the material represented the highest purity readily available in the bar size of $^5/_8$-in. diameter which was required. Other tension-impact tests were also initiated using specimens of rimmed and killed steels which had been heat treated to replace the lamellar carbides with those of spheroidal form. The latter study is being completed and will be reported in the near future.

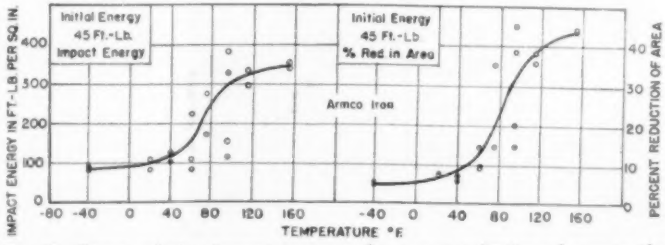


Fig. 18 Curves relating impact energy and per cent reduction of area to the temperature of the impact test of armco iron at an initial energy of 45 ft.-lb.

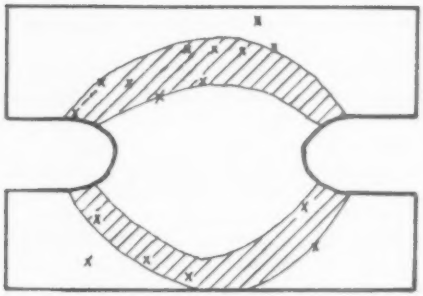


Fig. 19 Sketch showing region of maximum density of mechanical twins in armco-iron specimen subjected to impact load

X = Areas containing twins; scale: 1 in. = 5 mm.

The Armco iron was purchased in the cold-rolled condition and was heat treated, before machining the tension-impact specimens, according to the following schedule; normalized by heating to 1700° F., held 20 min. at temperature, air cooled then reheated to 1100° F. and furnace cooled for stress relief. The same Type B specimen design was employed to prepare the Armco iron for tests in tension impact made at initial-energy levels of 220, 110 and 45 ft.-lb. The complete results of tension-impact tests of Armco Iron are to be given in another report and the results for the 45 ft.-lb. initial energy level only are given in the curves of Fig. 18. The data for metallographic examination of partial fractures in Armco iron are given in Table 2.

DATA OBTAINED WITH ARMCO IRON

The most characteristic feature of the microstructure of partially fractured Armco iron specimens is the presence of mechanical twins in regions which suffer a low level of shear deformation. These regions are outlined as a band in the sketch of Fig. 19 and twin loci are seen to be regions of low stress at the fringes of the volume of material in the notch. A number of cleavage fractures were found in this region of several partial fracture specimens of Armco iron. Another specimen which was fractured at 60° F. with 45 ft.-lb. initial energy to give 222 ft.-lb./in.^{2} energy absorption as given in Fig. 18 showed a complete fracture in this region as illustrated in the macrograph of Fig. 20 even though this region was well outside of the region of maximum stress in the notch area. The fracture is seen to have traversed the region shown in Fig. 19 with highest frequency of mechanical twins. Several of the partial fracture specimens of Steel *Dn* also showed cleavage fracture regions in this same outer fringe of the shear area in the notch where a high frequency of mechanical twins was in evidence. The association of mechanical twinning with cleavage fracture is also brought out quite strikingly by the micrograph in Fig. 21 for the specimen of Armco Iron which was fractured outside of the notch as shown in Fig. 20. In this figure there is evidence that the cleavage fracture apparently started in the twin areas and propagated into the untwinned ferrite grain.

Fig. 20 Macrograph of specimen of armco iron fractured in region of maximum density of mechanical twins. Scale below shows $^1/_{10}$-in. intervals

SPECIAL BEHAVIOR OF KILLED STEELS

From Table 2 it can be noted that the fracture of the carbide lamellae in pearlite is the initial phase of fracture for the transition range in steels of rimmed, semikilled and fully killed grade. The fracture of pearlite in killed steels, however, does not in general lead to cleavage failure, as occurs in the rimmed and semikilled steels by stress concentration effects at the end of the sharp notch provided by the carbide fracture. There is instead, in the killed steels, the tendency to produce internal cavities or holes in the ferrite surrounding the pearlite fracture region, due possibly to the higher ductility and lower notch sensitivity of the ferrite in the killed steel.

The killed steels also show another marked difference from the rimmed and semikilled steels in that the frequency of formation of mechanical twins is of a much lower order. At lower temperatures of test at which pearlite fracture is not in as frequent evidence in the rimmed and semikilled steels, the frequency of mechani-

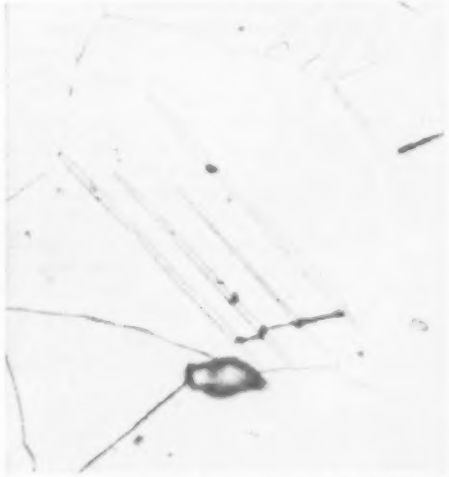


Fig. 21 Initiation of cleavage fracture in mechanical twins in armco iron. Etchant 5% nital, magnification 1500 × (Reduced $^1/_5$ in reproduction)

cal twinning increases in these steels and cleavage failure takes place with little shear deformation in the notch volume. At these same test temperatures the killed steels still show fracture of pearlite lamellae and another feature of the microstructure having the appearance of ferrite grain boundary twins begins to show. These areas are illustrated in Fig. 22 and are believed to be regions of mechanically twinned ferrite which are restricted to the grain boundaries. In the rimmed and

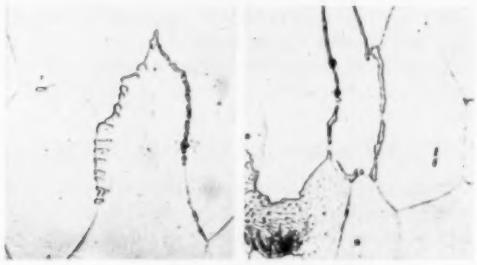


Fig. 22 Appearance of ferrite grain boundaries in killed steel subjected to impact load. Etchant 5% nital, magnification 2000 ×. (Reduced 1/2 in reproduction)

semikilled steels it was observed that mechanical twins also start at grain boundaries but have little difficulty in traversing the entire ferrite grain. At temperatures lower than the transition temperature range the twins formed in the killed steels do propagate through the entire ferrite grain. The relationship between mechanical twins and cleavage fracture has not yet been investigated as thoroughly for the killed steels as for the rimmed and semikilled steels.

SUMMARY

Observation of the microstructure of steel specimens loaded in tension impact may be summarized as follows:

1. The tension-impact fracture in the transition temperature range for all of the steels tested, was initially in the carbide lamellae.

2. There was evidence that for the rimmed and semikilled steels cleavage fracture may be the end result of a sequence of (*a*) pearlite fracture (*b*) mechanical twinning in the region of high stress at the cracks and (*c*) finally cleavage.

3. There was evidence of insensitivity of the killed steels to the second stage in the above sequence with respect to both temperature drop and twin frequency, and as a consequence the observed tendency of the killed steels to form internal cavities or holes at the cracks may be considered as a process of relief of high stress by plastic flow involving slip rather than twinning.

4. Several illustrations have been provided to show that mechanical twinning precedes cleavage fracture and that the cleavage may be initiated by the twin, or in the twin-deformed region.

5. The killed steels showed an outstanding difference from the rimmed and semikilled steels in the reluctance of the mechanical twins to propagate across the ferrite grain from one grain boundary to the other. For the rimmed and semikilled steels the twins usually extended over the entire grain diameter.

6. Mechanical twins which were propagated across the grain diameters of the killed steels made their appearance at considerably lower temperatures than was found for the rimmed and semikilled steels.

7. The transition temperature phenomenon in ferritic steels appears to be associated with the ease of formation of mechanical twins, their frequency, their ease of propagation across the grain diameter and the ease of cleavage initiation by the twins; all with respect to the temperature of the impact test.

8. It can be reliably stated that cleavage fracture terminates the high energy absorbing capacity of rimmed and semikilled steels at higher temperatures than for the killed steels. The higher twin nucleation temperature which the less thoroughly deoxidized steels possess is considered to be the chief factor responsible for their more easily produced cleavage fracture.

ACKNOWLEDGMENT

This work has been performed as part of the cooperative research contract between the Engineering Experiment Station of the University of Illinois, and the office of Naval Research, under Contract N6 onr-71, Task Order V. All work on this task is under the supervision of Dr. N. M. Newmark, Research Professor of Structural Engineering, University of Illinois.

The tests were conducted in the Department of Mining and Metallurgical Engineering with the assistance among others, of graduate students Mrs. M. Moran and T. S. Noggle and W. S. Jonsson and of senior undergraduate students V. B. Utzinger, R. J. Bruggen and D. L. Dyke.

References

1. Bruckner, W. H., and Newmark, N. M., "Axial Tension Impact Tests of Structural Steels," The Welding Journal, **28** (2), Research Suppl., 67-s to 88-s (1949); *Ibid.*, **29** (4), Research Suppl., 212-s to 216-s (1950).
2. Wilson, W. M., Hechtman, R. A., and Bruckner, W. H., "Cleavage Fracture of Ship Plates as Influenced by Size Effect," *Ibid.*, **27** (4), Research Suppl., 200-s to 207-s (1948); Boodberg, A., Davis, H. E., Parker, E. R., and Troxell, G. E., "Causes of Cleavage Fracture in Ship Plate-Tests of Wide Notched Plates," *Ibid.*, **27** (4), Research Suppl., 185-s to 199-s (1948).
3. Hones, A. P., *The Nature, Origin and Interpretation of Etch Figures of Crystals*, John Wiley & Sons, Inc. (1927).

Room Temperature Tensile Tests as an Index of Transition Temperature of Steel Plates

Paper suggests possibility of using reduction of area results as obtained from room-temperature round-bar tensile tests to predict transition temperatures of pressure-vessel steels

by Sadun S. Tör, Robert D. Stout and Bruce G. Johnston

INTRODUCTION

WHEN the Pressure-Vessel Research Project at Lehigh University was started four years ago it was with the purpose of studying and determining the effects of various fabrication processes on the steels used in pressure vessels. Ultimately, it was hoped that through this extensive study, not only would the general knowledge in this field be enlarged, but also data would result which the design engineer could make use of in pressure-vessel design. Two steels were selected and major parts of heats purchased. Four progress reports have already been published as a result of this program[1–4] in which studies of various notch-bend tests, the effects of plastic strain and post-heat treatments, and the effects of welding on these steels were reported. In this paper further analysis of the data as reported in one of the earlier papers, namely Progress Report No. 3 by Osborn, Scotchbrook, Stout and Johnston,[3] is presented, and it is indicated that deformations in the standard tensile test at room temperature are significantly related to the transition temperature of these and other steels.

A relationship between tensile-test results and transition temperatures has been sought previously. Recently, Dr. C. F. Tipper[5] in her paper "Correlation of Test Results," said, "...some relation between tensile-test results and notch-bend and notch-tensile results is to be expected whenever plastic deformation occurs." However, her data fail to substantiate this statement and she is forced to state in her conclusion, "the transition temperatures cannot be predicted from the tensile-test results, although low-transition temperatures are associated with high values of reduction in area."

Sadun S. Tör is Research Associate, Fritz Engineering Laboratory, Lehigh University. **Robert D. Stout** is Prof. of Metallurgy, Lehigh University, and **Bruce G. Johnston** is Prof. of Structural Engineering, University of Michigan, former Director of Fritz Engineering Laboratory, Lehigh University, Bethlehem, Pa.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

In this paper data are presented in a different manner and it is shown that, allowing for a rather uniform zone of scatter, a straight-line relation does exist between tensile-test results and transition temperatures.

MATERIAL

Steel Plates

Steel used in this investigation was aluminum-killed A.S.T.M. A-201 Grade A and Rimmed A.S.T.M. A-70 (now A-285) in $1^1/_4$ and $^5/_8$ in. thickness. Steel A-201 had 0.15 carbon and 0.53 manganese and Steel A-70 had 0.20 carbon and 0.35 manganese. (See reference 2 for further details.)

Plastic Straining

The $1^1/_4$-in. material in both steels was tested after the following permanent straining operations:

1	None
2	1% tension
3	5% tension
4	10% tension
5	1% compression

The $^5/_8$-in. material was tested only after operation 3.

Heat Treatment after Plastic Deformation

Material in each of the above strained conditions was tested after the following heat treatments:

1	Room temperature
*2	500° F.
3	800° F.
4	1150° F.
5	1600° F.

PROCEDURE

The materials used, and testing procedures were

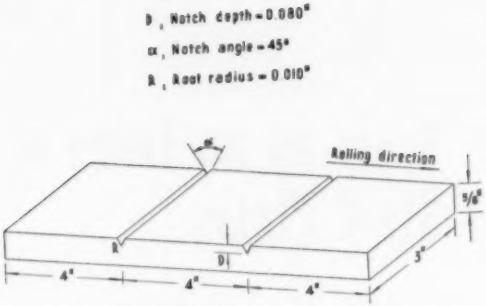


Fig. 1 Lehigh slow-notch-bend specimen

described fully in references 1–3; however, it may be pertinent to give a brief description of the Lehigh slow-notch-bend, Charpy, and tensile specimens, their treatments, and the testing methods, as adapted to the present program.

The Lehigh Slow-Notch-Bend Test

In Figs. 1 and 2 can be seen the specimen and the testing jig used to determine transition temperatures by the slow-bend method. The notches were machined in two cuts after the straining and heat-treating operations. The direction of plastic strain was in the direction of the long axis of the specimen. Transition curves were established by testing twelve double-notch specimens at various temperatures and observing the following criteria:

1. Total energy absorbed in breaking specimen.
2. Per cent cleavage in the fracture surface.
3. Per cent lateral contraction $^1/_{32}$ in. below the notch after fracture.

To obtain a transition curve and thus determine the transition temperature, each of the foregoing criteria was plotted against the temperature of the test, and the averages of the points at each temperature were joined by straight lines. The temperature corresponding to the point on the curve at 50% of the maximum value was defined as the transition temperature and was indicated by T_E for energy criterion, T_B for per cent cleavage fracture criterion and T_N for per cent lateral contraction under the notch criterion.

The Charpy Test

Standard V-notch Charpy specimens with a 0.08-in. deep notch and with the direction of plastic strain parallel to the long axis of the specimen were used. The notch direction was normal to the surface of the plate. Twenty-four specimens tested at six temperatures were used to plot the transition curve. Transition temperatures were determined in the same manner as in the Lehigh Slow-Notch-Bend Test.

Tensile Test

Standard 0.505-in. diameter tensile specimens machined subsequent to the same plastic strain and heat-treatment sequences were tested in duplicate and all the pertinent data were recorded.

Explanation of the Graphs

The relationship between the tensile specimens and the Lehigh slow-notch-bend or Charpy specimens was obtained by plotting the per cent reduction in area as obtained from the standard room-temperature tensile tests against transition temperatures in degrees fahrenheit as obtained from slow-notch-bend specimens or standard V-notch Charpy impact specimens. In addition T_N transition temperatures are plotted against:

$$e_b \text{ (total ductility)} = \ln (A_o/A_b)$$
$$e_u \text{ (uniform ductility)} = \ln (A_o/A_m)$$
$$e_n \text{ (necking ductility)} = \ln (A_m/A_b)$$

where:

A_o = initial cross-sectional area
A_b = cross-section area at breaking
A_m = cross-section area at maximum load

It should be borne in mind that the points on these graphs represent two different steels and 30 different treatments prior to tensile or transition-temperature tests. Hence a large variation in the resultant properties is represented.

Discussion of the Graphs

In Fig. 3, T_N lateral-contraction transition temperature as obtained by the Lehigh slow-notch-bend specimen is plotted against the reduction in area. The reduction in area values cover a range of 20% (from 50 to 70%) and the transition temperature covers a range of 200° F. (from −120 to +80° F.). The relationship is a straight line with some scatter. The scatter is of the magnitude to be expected from this type of data. In Fig. 4, T_N transition temperature as obtained from V-notch Charpy specimens are plotted against per cent reduction in area. The curve from

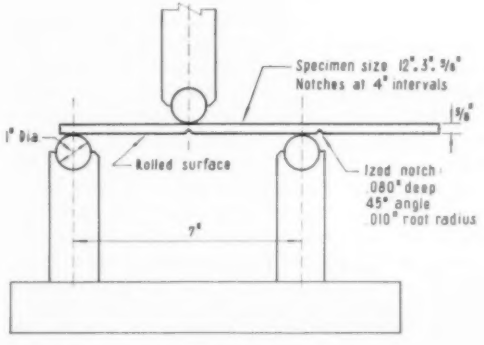


Fig. 2 The Lehigh slow-notch-bend test

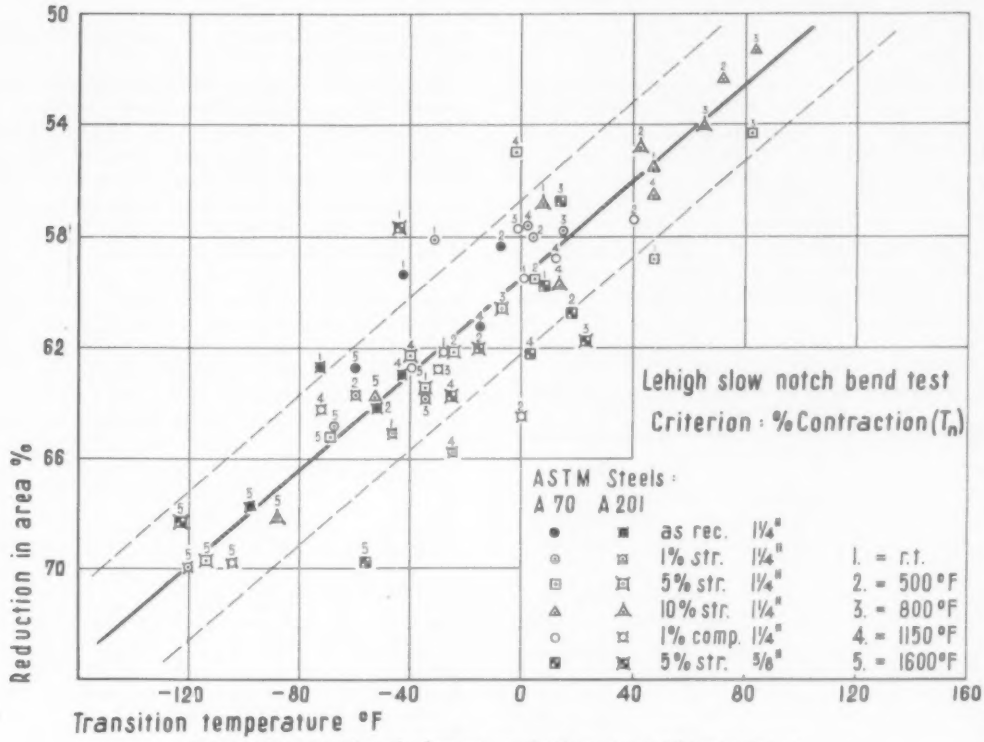


Fig. 3 A70 and A201 steels after various plastic strains and heat treatment

Relation between reduction in area and transition temperature

Fig. 3 is superimposed here to afford a better comparison between the two tests. The Charpy transition temperatures are roughly 90° F. higher than those obtained for similarly treated steel by the Lehigh slow-notch-bend test. Figure 5 shows the relation between Lehigh slow-notch-bend and V-notch Charpy transition temperatures where per cent contraction under the notch is used as criterion.

It can be seen that in spite of the scatter there is a definite correlation between the two test methods. In Fig. 6, per cent reduction in area values are plotted against the energy-transition temperature as obtained from V-notch Charpy specimens with the energy absorbed during test used as criterion. The resulting straight line is practically the same as in Fig. 4. However, the points are bunched together indicating that the energy criterion for use in transition temperature determination with the Charpy specimen is not as sensitive to changes in strain or heat treatment as per cent contraction under the notch measurements.

In Fig. 7, ϵ_b (total ductility) has been plotted against Lehigh slow-notch-bend transition temperature T_s. Here again the straight-line relationship is in evidence. However, when ϵ_b and ϵ_u, uniform ductility and necking ductility, respectively, are plotted against transition temperatures T_s—Figs. 8 and 9, the relation is obscured by excessive scatter.

Fracture appearance used as a criterion for transition-temperature determination is not as sensitive as either the energy criterion or per cent contraction criterion in the Charpy or Lehigh slow-notch-bend tests. In Fig. 10, transition temperatures as determined by fracture appearance defined as per cent cleavage has been plotted against per cent reduction in area values

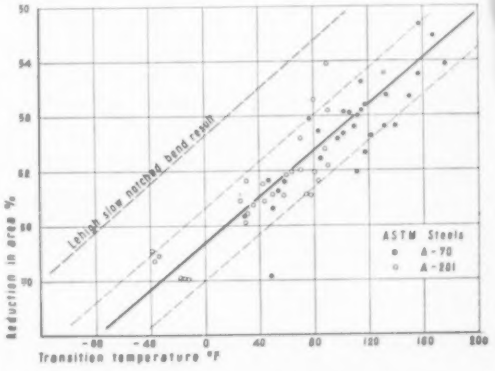


Fig. 4 Relation between transition temperature and reduction in area

V-notch Charpy test criterion: per cent contraction. A70 and A201 steels after various plastic strains and heat treatment

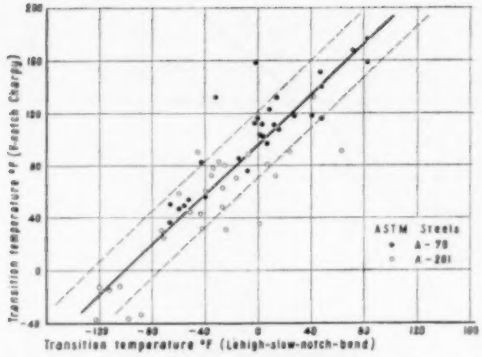


Fig. 5 Relation between V-notch Charpy and Lehigh slow-notch-bend transition temperature

Criterion: per cent contraction. A70 and A201 steels after various plastic strains and heat treatment

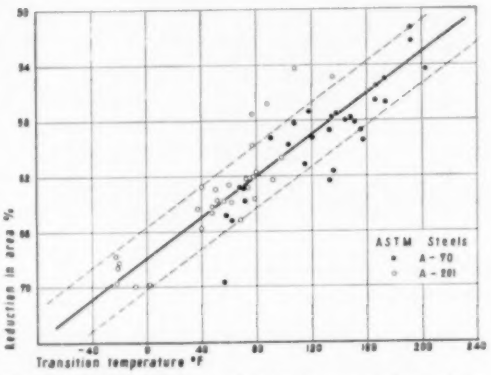


Fig. 6 Relation between reduction in area and transition temperature

V-notch Charpy test. Criterion: Energy absorbed. A70 and A201 steels after various plastic strains and heat treatment

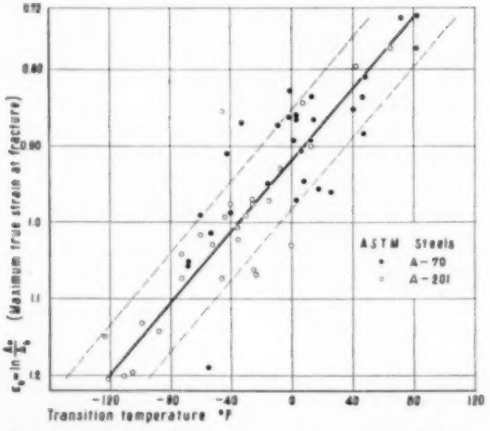


Fig. 7 Relation between ϵ_{fs}, maximum true strain at fracture and transition temperature

Lehigh slow-notch-bend test. Criterion: per cent contraction. A70 and A201 steels after various plastic strains and heat treatment

obtained from tensile tests. The relationship is not of the straight-line type but rather curvilinear.

Up to this point all of the data presented have been confined to the results of the research performed at Lehigh University. However, it was considered desirable to survey the transition-temperature literature to uncover some substantiating data suitable for plotting per cent reduction in area against transition temperature. Such data were found in the A.S.M. Campbell Memorial Lecture of 1947[6] delivered by Dr. A. B. Kinzel. The Kinzel slow-notch-bend specimen, Fig. 11, and testing jig, Fig. 12, are very similar to those used in the Lehigh slow-notch-bend method. The main differences in the test specimens are in the plate thickness and the V-notch depth; the Kinzel specimen was $^1/_2$-in. thick and the V-notch was 0.05 in. deep; whereas the Lehigh specimen as used in the Pressure-Vessel Re-

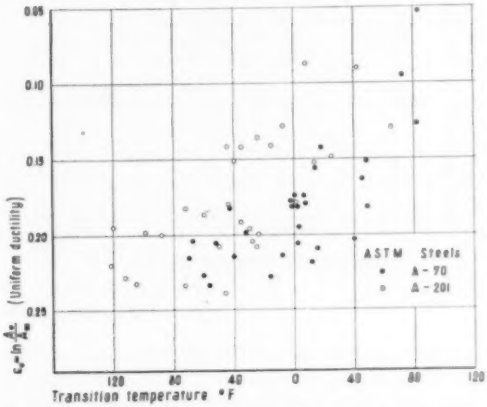


Fig. 8 Relation between ϵ_u (uniform ductility) and transition temperature

Lehigh slow-notch-bend test. Criterion: per cent contraction. A70 and A201 steels after various plastic strains and heat treatment

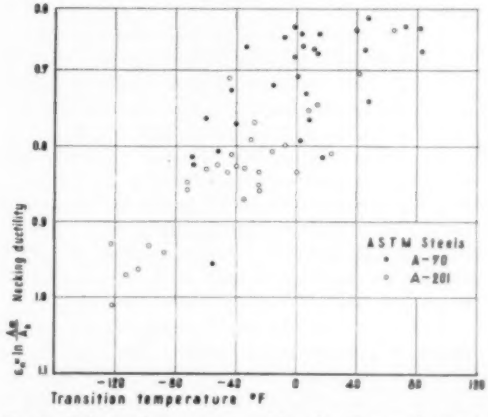


Fig. 9 Relation between ϵ_n, necking ductility and transition temperature

Lehigh slow-notch-bend test. Criterion: per cent contraction. A70 and A201 steels after various plastic strains and heat treatment

search Program was $^1/_8$ in. thick with 0.08-in. deep V-notch. The differences in the testing jig are the specimen support span which is $4^1/_2$ in. in the Kinzel jig and 7 in. in the Lehigh jig and the ram tip which in the Kinzel jig has a radius of $^1/_4$ in. and in the Lehigh jig a $^1/_2$-in. radius.

It is noteworthy, however, that contraction under the notch was used as a criterion for transition temperature determination and also both tensile and slow-notch-bend tests were performed on a great variety of steels ranging from plain carbon to alloy. Moreover, the fact that both of these tests were performed on steels similarly treated enables one to make a correlation study similar to that carried out for the Lehigh data.

The data from the Kinzel[6] paper are plotted in Fig. 13. The per cent reduction in area values are obtained from room-temperature tensile tests and the transition-temperature values are obtained from the Kinzel slow-notch-bend specimen using the under-notch contraction as criterion. It should be noted that Kinzel used the temperature corresponding to 1% contraction in the transition curve as his transition temperature. Therefore, his temperature values appear lower than the Lehigh values. To permit a comparison of this straight line, Lehigh transition temperatures were redetermined

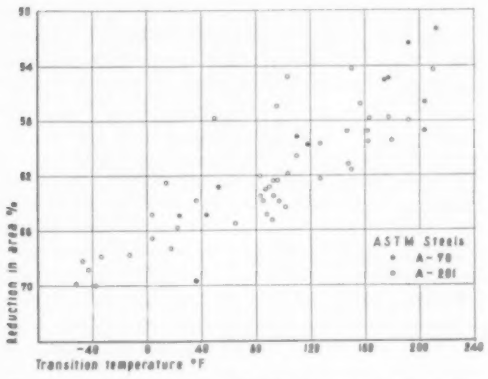


Fig. 10 Relation between reduction in area and transition temperature

Lehigh slow-notch-bend test. Criterion: per cent cleavage. A70 and A201 steels after various plastic strains and heat treatment

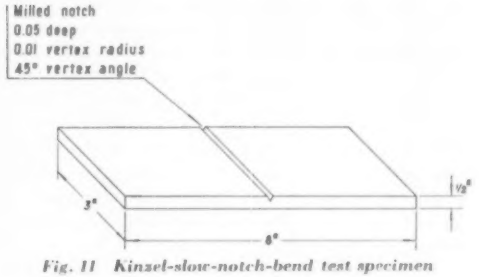


Fig. 11 Kinzel-slow-notch-bend test specimen

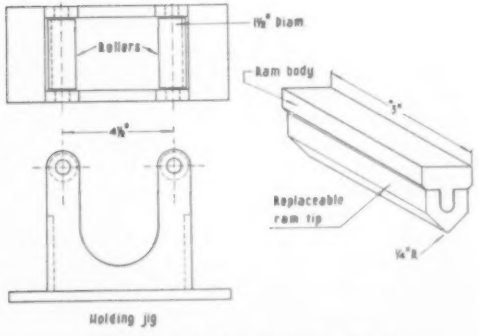


Fig. 12 Jig for Kinzel slow-bend test

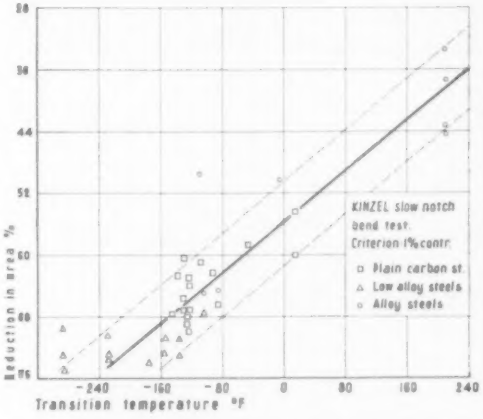


Fig. 13 Relation between transition temperature and reduction in area

Kinzel slow-notch-bend test. Criterion: 1% contraction. Plain carbon, low-alloy and alloy steels as-received and as-normalized.

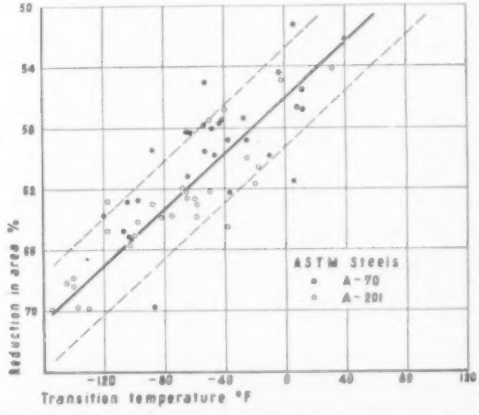


Fig. 14 Relation between transition temperature and per cent reduction in area

Lehigh slow-notch-bend test. Criterion: 1% contraction. A70 and A201 steels after various plastic strains and heat treatment

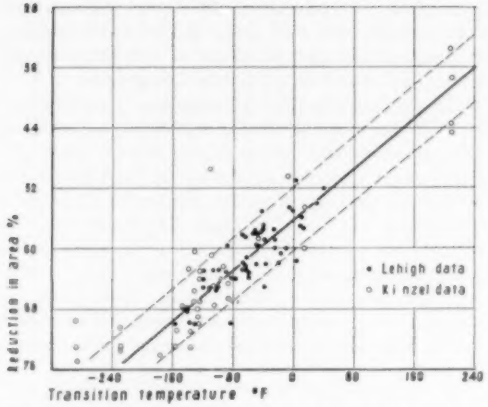


Fig. 15 Relation between per cent reduction in area and transition temperature from the Lehigh and Kinzel slow-notch-bend-test data. Criterion: 1% contraction

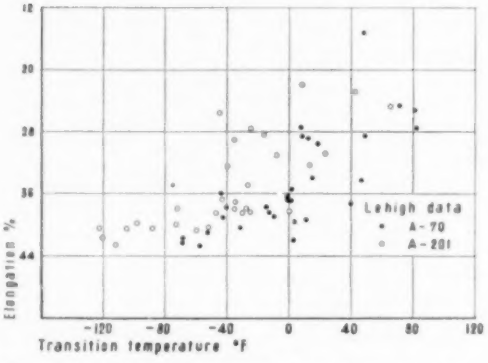


Fig. 16 Relation between elongation and transition temperature

Lehigh slow-notch-bend test. Criterion: per cent contraction A70 and A201 steels after various plastic strains and heat treatment

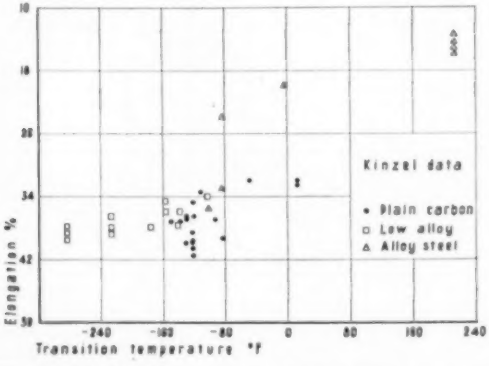


Fig. 17 Relation between elongation and transition temperature

Kinzel slow-notch-bend test. Criterion: 1% contraction. Plain carbon, low-alloy and alloy steels as-received and as-normalized

from the original transition curves, at 1% contraction. When the Lehigh per cent reduction in area values are replotted against these transition temperatures in Fig. 14, it becomes obvious that they lie practically on the same line as the Kinzel data, Fig. 15. It should be noted that three groups of steels are represented in the Kinzel data and therefore, a wide range of reduction in area and transition temperature values are present. It is interesting that the Lehigh values which represent two plain low-carbon steels should fall on the same curve as the carbon and alloy steels of the Kinzel data.

When per cent elongation data are substituted for reduction in area, as in Figs. 16 and 17, the transition temperatures (per cent contraction criterion) no longer fall into a satisfactory correlation with the tensile results of either Lehigh or Kinzel.

CONCLUSION

The curves presented in this paper show that, allowing for a band of scatter, there is definitely a straight-line relationship between tensile-test results, and Charpy or slow-notch-bend transition temperatures. Particularly, this is true of the correlation between percent reduction of area values obtained from the standard tensile-test specimens and the transition temperatures as obtained using lateral contraction as criterion. Moreover, this relationship is substantiated by an analysis of results from similar tests conducted by Kinzel[6] at an earlier date.

These curves, therefore, lead one to the conclusion that reduction in area as determined by a tensile test may have more significance than is generally realized. If interpreted in this manner it has the advantage of requiring only a few tensile tests as compared to 24 notch-bend tests needed for transition-temperature determination. The ultimate aim in this type of correlation would be to substitute the standard tensile test where the many limitations of the V-notch bend specimens such as the severity of the notch, the condition of the notch bottom, the speed of bending, etc. are absent. Moreover, the tensile test is relatively easy to perform and is universally accepted.

William and Ellinger[7] have shown that plates from Liberty ships in which fractures occurred possess an average of from 6 to 12 ft.-lb. V-notch Charpy values when tested at the temperature of the ship failure. If such a criterion of energy level can be applied to pressure vessels, then it would mean that a steel which has a V-notch Charpy value lower than some specified value at temperatures at which the finished pressure vessel will operate, would be unsatisfactory. Using this specified energy-level criterion, V-notch Charpy transition temperatures could be determined on a number of steels and treatments and plotted against per cent reduction in area (obtained from room-temperature tensile tests) on the same steels. A direct correlation between the operating temperature of the pressure vessel and the per cent reduction of area required in the steel would thereby be established. In

the fabrication of pressure vessels, the steel is subjected to certain bending, pressing or welding or combination of these operations with the accompanying lowering of the ductility. This loss in ductility could be determined by the design engineer, and before the tensile tests are made, the material could be strained by this amount. Alternatively, the reduction in area after such a prestrain might be predicted by reference to a complete true stress-strain curve of the material. In this way the per cent reduction in area determined by the tensile test would more or less represent those portions of the pressure vessel that were strained and therefore retain less available ductility. The transition temperature corresponding to the reduction in area as determined by the above method would then indicate the suitability of that particular steel for use in a pressure vessel at that temperature.

It would be of major interest to determine if the same type of relationship would hold true if flat-bar tensile specimens were used instead of round bar.

It is hoped that other investigators will determine the relationships reported herein and that future work be guided along these lines. It would be desirable to obtain tensile and transition-temperature data from pressure vessels that have failed.

SUMMARY

Straight-line relationships have been shown to exist between room temperature round-bar tensile-test results and transition temperatures as determined by Lehigh slow-notch-bend, Kinzel slow-notch-bend and V-notch Charpy methods. The possibility of using room-temperature tensile tests to predict transition temperatures of pressure-vessel steels has been indicated.

ACKNOWLEDGMENTS

This work was sponsored by the Pressure-Vessel Research Committee of the Welding Research Council, which is directed by William Spraragen. P. R. Cassidy is chairman of the Pressure-Vessel Research Committee and Boniface E. Rossi is executive secretary. F. L. Plummer is chairman of the Fabrication Division of the Pressure-Vessel Research Committee, which guided the project staff in this work.

The project was carried on jointly by the Fritz Engineering Laboratory of the Civil Engineering Department, and the Metallurgy Department of Lehigh University.

The execution of work was made possible by the cooperation of Kenneth R. Harpel, laboratory foreman, and the entire laboratory staff.

References

1. Osborn, C. J., Scotchbrook, A. F., Stout, R. D., and Johnston, B. G., "Comparison of Notch Tests and Brittleness Criteria," THE WELDING JOURNAL, **28** (1), Research Suppl., 24-s to 33-s (1949).

2. Osborn, C. J., Scotchbrook, A. F., Stout, R. D., Johnston, B. G., "Composition and Property Variation of Two Steels," *Ibid.*, **28** (5), Research Suppl., 227-s to 235-s (1949).

3. Osborn, C. J., Scotchbrook, A. F., Stout, R. D., Johnston, B. G., "Effect of Plastic Strain and Heat Treatment, *Ibid.*, **28** (8), Research Suppl., 337-s to 353-s (1949).

4. Scotchbrook, A. F., Eriv, L., Stout, R. D., Johnston, B. G., "Effect of Welding on Pressure-Vessel Steels," presented at the A.S.M.E. Annual fall meeting, New York City, Nov. 27, 1949. (July, 1950, *Transactions*, A.S.M.E.)

5. Tipper, C. F., "Correlation of Test Results," THE WELDING JOURNAL, **29** (2), Research Suppl., 50-s to 57-s (1950).

6. Kinzel, A. B., "Ductility of Steels for Welded Structures," *Trans. Am. Soc. Metals* **40**, 27-82 (1948).

7. William, M. L., Ellinger, G. A., "Investigation of Fractured Steel Plates Removed from Welded Ships," presented at fall meeting, 1947 of A.W.S. in Chicago; recently distributed as progress report by Ship Structure Committee, Serial No. NBS-1 (Feb. 25, 1949).

Distribution of Locked-In Stresses in a Large Welded-Steel Box Girder

Methods of determining residual stresses in large heavy-welded box girders. Stresses vary from high tension to moderate compression

by John Vasta

Abstract

A large welded box girder, made of relatively thick plates and embodying a high degree of constraint, was fabricated and then trepanned for the purpose of determining the distribution of the locked-in stresses. These stresses were obtained by the relaxation method, and changes in strain were measured by means of SR-4 electrical strain gages. The girder was subdivided at four transverse sections. This paper gives the distribution of the locked-in stresses and discusses strain-gage drift and other factors affecting the probable accuracy of the data. Also treated are the limitations of a quasi-destructive method as a tool for determining locked-in stresses.

John Vasta is Head, Hull Design Scientific Section, Bureau of Ships, Navy Dept., Washington, D. C.

Scheduled for presentation at the Thirty-first Annual Meeting, A.W.S., Chicago, Ill., week of Oct. 22, 1950.

INTRODUCTION

HIGH constraint in structural members caused by their geometrical shapes has been generally regarded as having a significant effect on the structural behavior of large and heavy weldments. The inherent rigidity in these heavy structures has been considered responsible for creating residual, multiaxial stresses which, under certain combinations of low temperature and high rate of straining, could cause failure of the structure even when average stresses are low. To study the effects of this constraint, a series of tests was made on large, welded-steel box girders. These were about 23 ft. in length and 2 ft. square in cross section, weighing approximately 9 tons each. The project was initiated

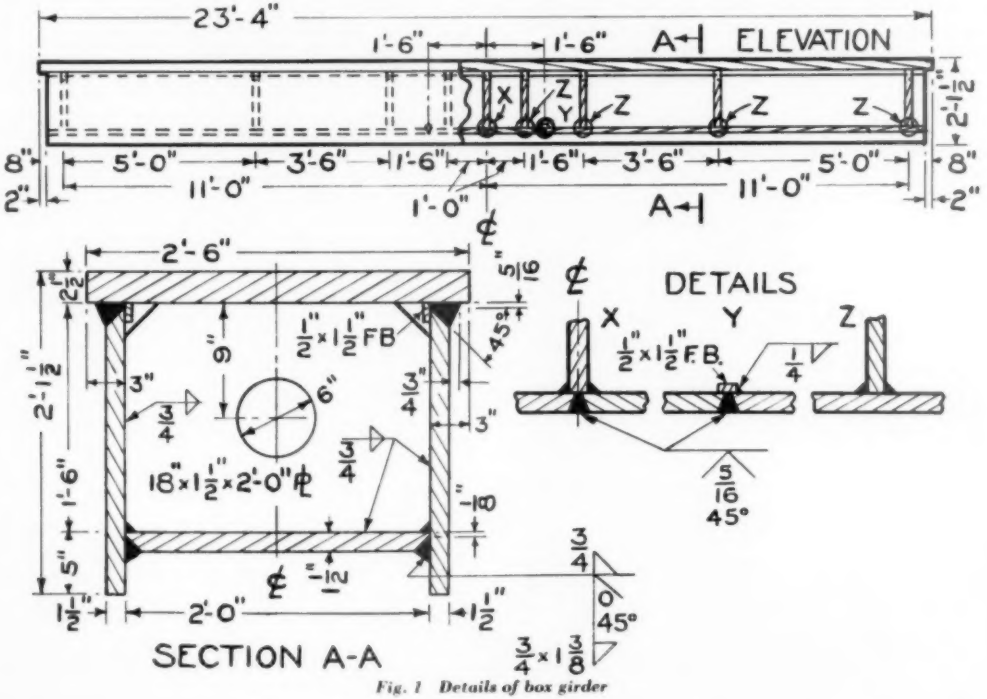


Fig. 1 Details of box girder

several years ago by the Welding Research Council as part of the broad research program stimulated by the ship fracture problem.

In all, six girders were constructed. The first was tested in bending at room temperature. This specimen carried practically the full calculated load based on the modulus of rupture, and deflected 6 in. before finally failing in a brittle mode. As the importance of the welding residual stress on the behavior of welded structure gave ground to that elusive property of steel—notch sensitivity—the test program was reoriented to explore the latter. Accordingly, the next four girders were tested at various temperatures ranging from −40° F. to room temperature. By keeping design, material and fabrication and welding sequences constant, it was possible to evaluate the structural performance of these girders as a function of the testing temperature.

The results of these structural tests have been reported in the March 1949 issue of *Welding Research Supplement*.[b] * It should be remembered that in these tests it had been assumed that the degree of constraint existing in the specimens was large, implying that there were present high residual stresses in the welds, and possibly equally high locked-in stresses in the plate components of the girders. To obtain a quantitative value of these initial stresses, it was decided to construct one additional girder, the sixth of the series, to the same specifications as the previous ones. This sixth specimen was not to be tested by loading in bending, but was to be subdivided at four transverse cross sections in order to determine the state of the locked-in stresses by the relaxation method. The underlying assumption here was that the locked-in stress measured in the sixth box girder would be representative of the value existing in the previously tested specimens. Locked-in stress[3] is defined as that stress set up in a structural member by restraints arising from fabrication and assembly processes. Because of the method of testing used, complete dismemberment of the girder resulted. This paper gives the results of the analysis of the changes in strains measured on relaxing, i.e., trepanning the various blocks from the girder; with a discussion of the most significant findings.

* Numbers in parentheses indicate references given at the end of the report.

GENERAL FEATURES OF THE TEST

The structural details of the box girder, its dimensions and general fabrication details are given in Fig. 1. Changes in strains were read by means of SR-4 rosette electric strain gages at the locations shown in Fig. 2. Four transverse girths, identified as sections 1–4 disposed symmetrically in relation to the mid-length of the girder, were investigated. Figures 3 and 4 show the outline and dimensions of the trepanned blocks which were cut from the girder by means of drilling small overlapping holes along their peripheries. Typical blocks are seen in Figs. 5 and 6.

Strains were required on the inside faces of the plates, as well as on the outside. The internal gages were installed before closing up the girder, Fig. 7. The necessary wiring connecting the gages to the strain indicators was led through the lightening holes provided in the transverse

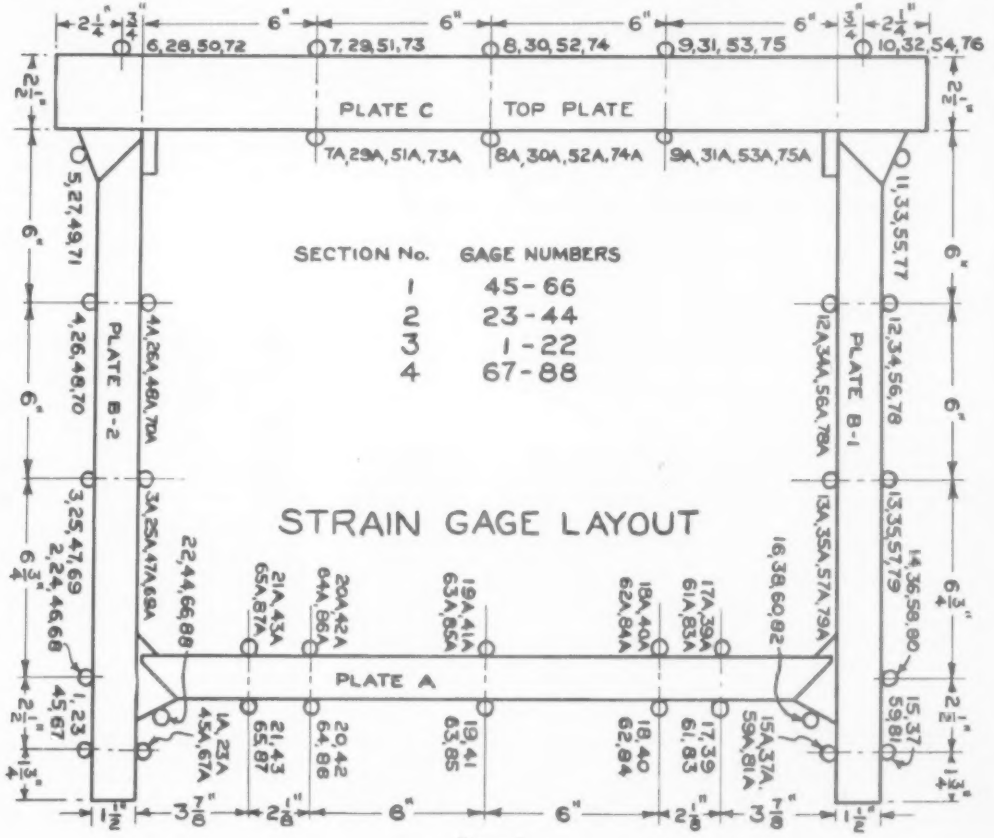


Figure 2

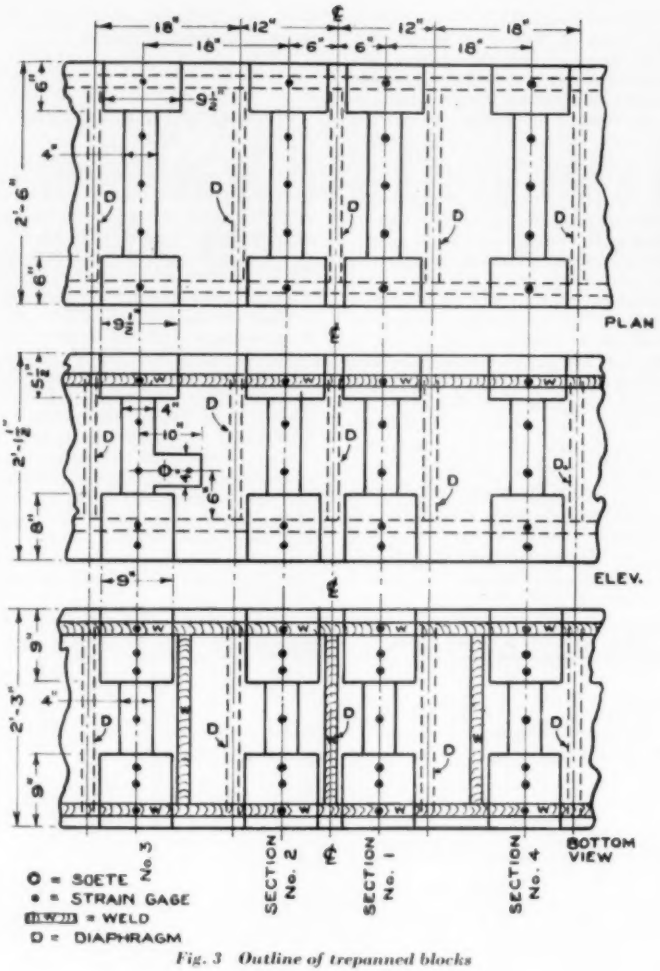


Fig. 3 Outline of trepanned blocks

Fig. 4 View showing how trepanning was accomplished

White areas indicate protective mask for strain gages

diaphragms, Fig. 8. This figure also shows the girder supported on special jigs to facilitate drilling. The girder, completely sectioned, is seen in Fig. 9. Note that the severed sections are held together by two tack-welded bars.

At each of the four transverse sections, changes in strain were recorded at 22 gage locations, this number being considered the minimum to give a reasonable distribution of the locked-in stress for the girth. At fourteen of the 22 strain gage stations strains were measured on both sides of the plate, four gages were located at the outside corner welds, and the remaining four were placed opposite the welds of the T-joints.

Approximately two months, July and August 1948, elapsed from the time when the inside strain gages were installed to the time when the box girder was ready for subdivision. The complete trepanning operation required two more months. Changes in strain were obtained by taking initial measurements on all the gages just prior to starting the trepanning operation, and reading final strains immediately after each block was removed from the girder. In this manner the time increment between the initial and final strain readings became a variable one; a matter of a few hours for the first block trepanned and about two months for the last one. From this spread of testing time it would seem that there was ample opportunity for some strain gage drift. This question is discussed in detail later on.

ANALYSIS OF DATA

The strain differences between initial and final readings were converted to stresses by means of the well-known elastic stress equations, Appendix A. For this calculation, a Young's modulus of $29^1/_2$ million psi., and a Poisson's ratio of 0.3 were assumed. In converting strain to stress, elastic behavior was considered throughout even in the few cases when the resulting stresses appeared to be higher than the elastic limit of the material. This is believed to be justified because a relaxation stress is essentially an elastic one. Where strain was measured on both sides of the plate, the strain differences were averaged before converting to stress. Only longitudinal and transverse locked-in stresses were computed, these being considered as having the most practical significance. The calculated stresses are tabulated in Appendix B.

RESULTS AND DISCUSSION

The distributions of the longitudinal locked-in stresses determined at the four transverse sections are presented graphically in Figs. 10–13 inclusive. The plots are strikingly similar and show a reasonably consistent pattern from section to section. The stresses for the four sections have been averaged and are shown in Fig. 14. This averaged distribution may be considered as typical for the girder. It shows that the stresses in the web plates vary from a very high-tensile residual stress (of the order of the yield point of the material) at the upper corner welds, to a moderately high locked-in compressive stress of about 20,000 psi. at mid-height of the girder. The thick, top flange plate is the most irregular in its behavior; the stresses vary considerably from section to section, although in the main they retain their compressive character. Of particular interest is the behavior of the lower flanges and the bottom corner welds. The entire width of the bottom plating

Fig. 5 Typical upper corner T blocks removed from girder

Note strain gages and internal wiring

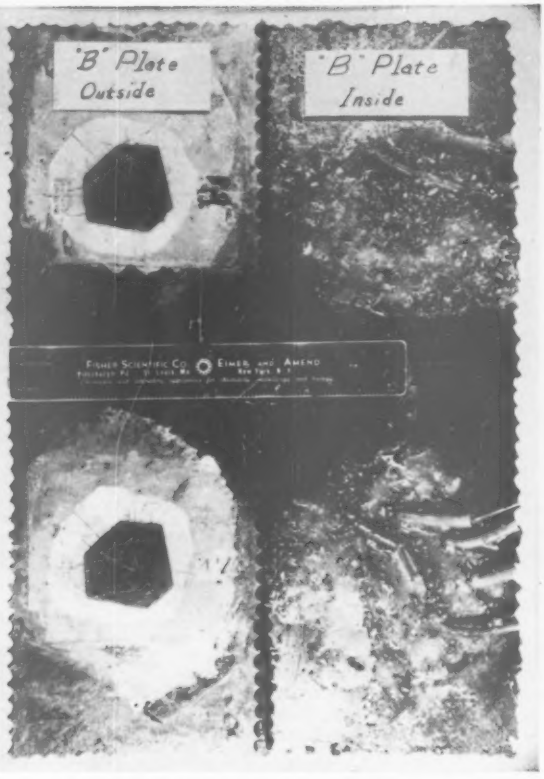


Fig. 6 Typical blocks trepanned from side plates

Right view shows the internal wiring

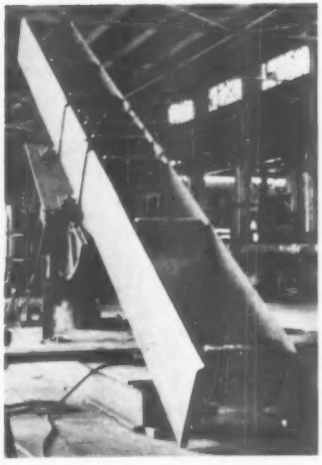


Fig. 7 Girder before addition of top cover plate, showing internal diaphragms

appears to be in a state of longitudinal tension, with a mean intensity of approximately 13,000 psi. The lower corner weld stresses are moderate, 22,000 to 28,000 psi. tension instead of the yield point intensity. These relatively low welding stresses may have been considerably influenced by the welding sequence used in fabricating the girder. It is significant that the top flange plate was welded last, making the upper corner welds the closing ones. Any secondary bending stresses induced

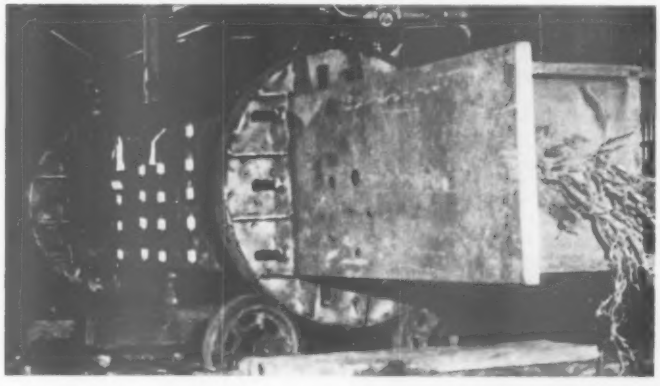


Fig. 8 Box girder supported on special fixture preparatory to trepanning

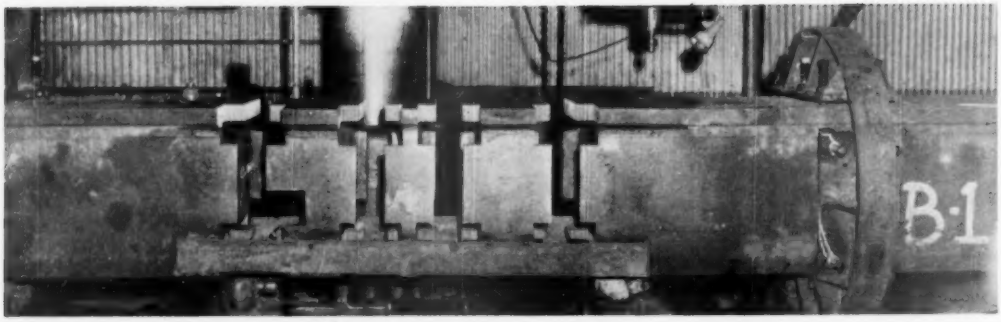


Fig. 9 Box girder completely sectioned

The various elements held together by tack-welded bars

by this last operation may have partially relieved the welding stresses at the lower corners.

The distribution of the transverse locked-in stresses is somewhat similar to that of the longitudinal one except that the stresses at flanges of the girders are of opposite sign. At the upper corner welds, tensile stresses approach the yield point. Across the top flange, stresses are moderate and fairly uniform, about 18,000 psi., but this time tension predominates. The bottom flange shows tension at the edges, changing to slight compression across the center. There was good agreement between points located symmetrically with respect to the vertical axis. No check of the balance of forces and moments is possible in this case because of the unknown stresses developed in the internal diaphragms. The discussion pertaining to the reliability of the strain data, therefore, is confined to the longitudinal stresses.

Since the box girder is in equilibrium and no external forces are applied, the longitudinal strain data should satisfy two basic requirements: equilibrium of internal forces, and equilibrium of internal resisting moments. In order that there should be no translation, the sum of the tensile forces must equal the sum of the compressive forces. Based on the averaged stress distribution of Fig. 14, the calculated internal compressive forces balance the tensile forces within 5%, a figure well within the limits of experimental accuracy. The agreement, however, is not so good with regard to the internal resisting moments. To satisfy the requirement that there be no rotation, the net internal resisting moment about a system of orthogonal axes must also be zero. The calculated internal resisting moment about the vertical axis, which is the axis of structural symmetry, balances within 8%, but the moment about the horizontal axis is unbalanced by about 20%, Fig. 15.

The discrepancy in resisting moment about the horizontal axis admittedly is high. However, even a 20% unbalance may be considered reasonable under the

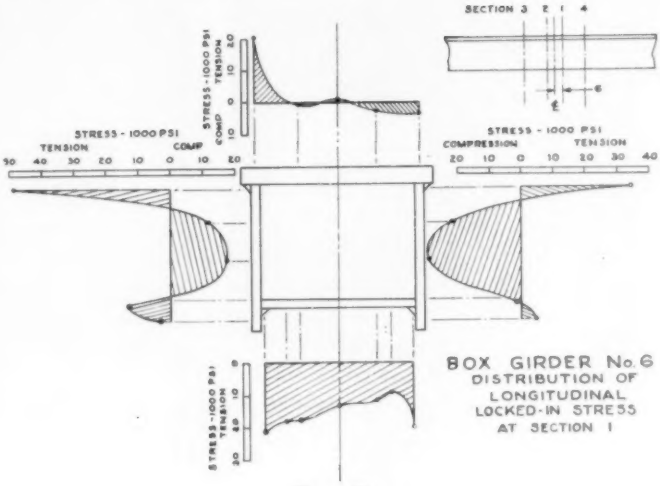


Figure 10

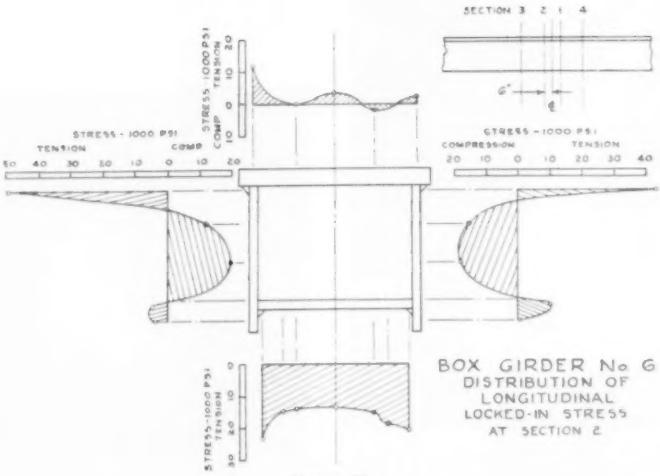


Figure 11

circumstances, for the reasons discussed herewith:

1. The experimental points in Fig. 14 are not numerous enough to fully establish the shape of the stress distribution curves. It is entirely feasible to draw through these points fair stress curves which do not disturb the balance of the internal forces, and yet affect the balance of the resisting moment about the horizontal axis by 3 to 5%.

2. In order to arrive at the locked-in forces and moments, the stress intensities were multiplied by the nominal cross-sectional areas of the girder components. Variations in plate thickness of the order of commercial tolerances can influence the resisting moment calculation by as much as 3%.

3. The strain data are accurate, at best, to ±20 micro inches per inch. This means that the stress intensity could be in error by a spread of about 1200 psi. A variation in the stress curves of this amount can affect the resisting moment by 3%.

4. In addition to these tangible factors, there are others which are much more difficult to evaluate. For example, any rolling stresses that may have been present in the plates are reflected in the relaxation strains. In this regard it may be recalled that rolling stresses have a variable distribution through the thickness of the plate. Experimental work[3] has shown a steep stress gradient at the surfaces changing in sign at the central core of the plate. The same shape of stress distribution has been measured through the thickness of a welded joint.[4] In the technique for determining stresses by averaging the readings measured on opposite surfaces of the plate, it is usually assumed that the stress varies linearly through the thickness of the plate. From references 3 and 4, it would appear that this simplified assumption has not been corroborated by tests. It can be inferred that if the distribution and intensities of the rolling stresses are identical in the top and bottom flanges of the girder, their effects would tend to neutralize each other, but because of the difference in plate thicknesses this cannot be accepted as a proven fact. Therefore the effect of rolling stresses remains an unknown quantity.

While many of the above factors may be minor in themselves, their cumulative effects could account for the unbalanced moment observed in this study. It is believed that the data portray the distribution of the locked-in stresses with an accuracy within the inherent limitations of the experimental technique employed.

STRAIN GAGE DRIFT

After the gages were installed, approximately two months elapsed before the box girder was completely subdivided and all strains were read. Since all the gage sta-

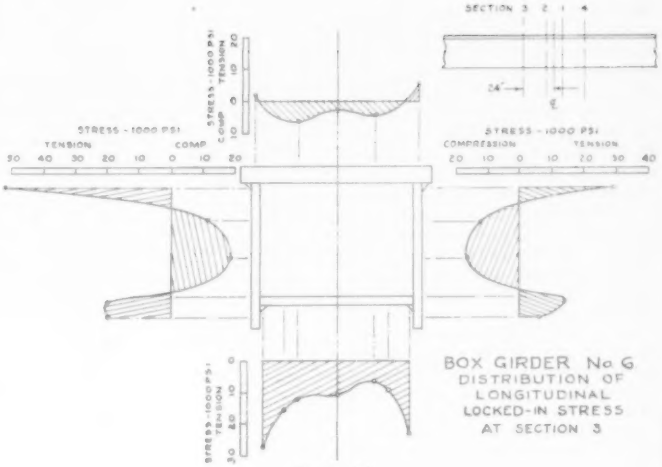


Figure 12

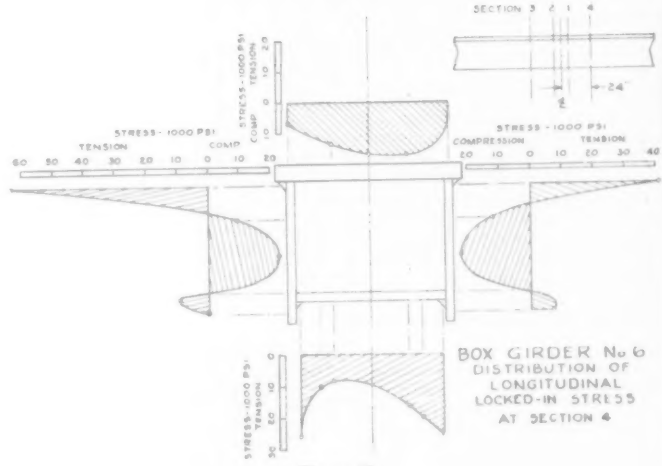


Figure 13

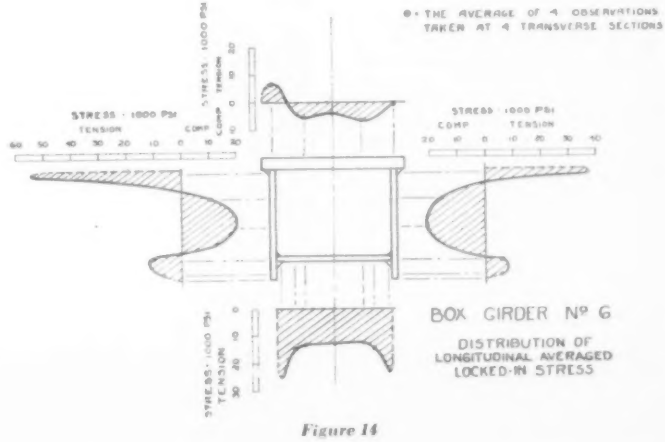


Figure 14

tions could not be sectioned and read simultaneously, the distribution of the stresses presented herein could be in error by the amount that the strains may have drifted with time. Only that drift which may have occurred between the initial and final strain readings (after trepanning) would affect the reliability of the data. The reasons for strain-gage drift are still obscure, though some of the elements contributing to it are known. While making spot checks on some of the blocks already trepanned, it was discovered that in some instances a significant strain change had occurred. Naturally, this raised the question as to whether the additional change was due to further relaxation of the locked-in stress, or merely represented strain-gage drift caused by gage instability. To explore this possibility further, several blocks were selected at random for additional observation of changes in strain with time. These observations covered a period of approximately three months. While every effort has been made to interpret the additional data, the information gathered is somewhat inconclusive and precludes formulating an orderly pattern of variation of strain with time, temperature or even humidity. For example, at Station 75 the change in strain taken immediately after trepanning indicates a compressive longitudinal stress of 17,200 psi. The strains recorded three months later correspond to a calculated stress of about 10,500 psi., and those measured three weeks after that indicate a compressive stress of 17,100 psi. Not all the strain gages studied behaved in a similar manner, as seen from the following table:

Station No.	*After trepanning, 10/28/48*	*Locked-in Stresses, psi. 11/18/48*	*2/3/49*
75	−17,200	−10,500	−17,100
48	−11,700	−3,100	−6,500
65	+18,200	+27,000	+24,800
10	+5,400	+12,400	+19,900

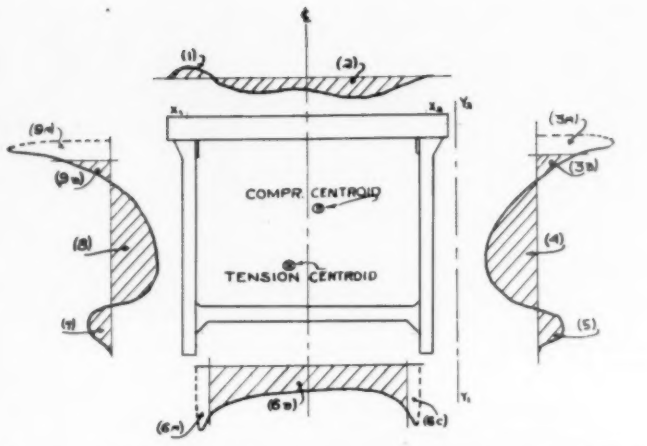
Although the data do not support a positive statement on whether or not the changes in strains reflect additional relaxation, the indications are that they do not. An evaluation of the over-all behavior of the box girder favors the conclusion that the stress distribution obtained immediately after trepanning is fairly accurate, and represents a much more realistic distribution than one that could have been determined from relaxed strains read months later. This conclusion finds support in the consistency and symmetry of the stress-distribution pattern, and in the reasonable balance of the internal forces and resisting moments.

QUASI-DESTRUCTIVE METHOD FOR DETERMINING LOCKED-IN STRESSES

One of the chief disadvantages of trepanning plugs and large blocks from a welded assembly is the inevitable dismemberment of the structure, Fig. 9. Recent methods have been proposed which feature drilling a small diameter hole, and reading the resulting deformations by means of strain gages attached to the structure proper adjacent to the hole. These methods appear to be a compromise between the destructive method typified by trepanning relatively large plugs, and the nondestructive method typified by the X-ray diffraction technique. Opportunity was taken in this study to check the accuracy of the quasi-destructive method. Small diameter holes (1/4 in.) were drilled in the side plates of the girder, near section 3, Figs. 16, 17, and strains were recorded. These strains were then used with the analytical expressions developed by Soete[5] and Riparbelli,[6] Appendix A, and the calculated stresses were compared with those obtained from the relaxed strains measured on the large trepanned blocks.

The following table sumarizes the stress intensities computed by the three methods investigated.

From the above tabulation it is seen that there are significant discrepancies between the stresses calculated from the theories of Soete and Riparbelli and the stresses obtained from strains measured on the trepanned blocks. It is believed, however, that this discrepancy does not constitute a basic error in the theory, but reflects instead the imperfections of the experimental techniques in their present state of development.



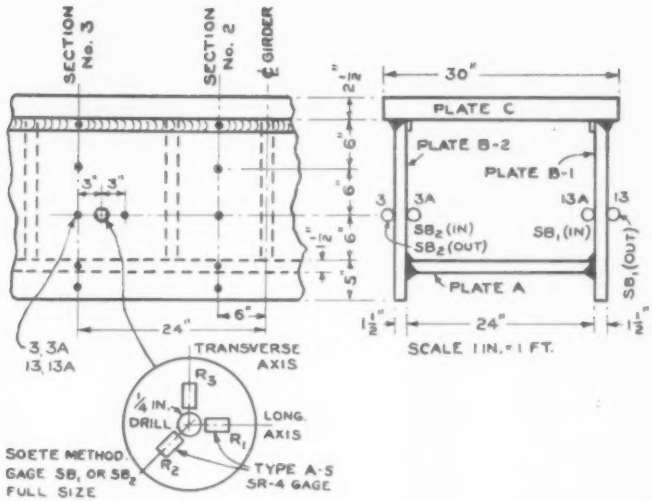
PT.	FORCES TENSION	FORCES COMPR.	MOMENTS ABOUT X, X₂ OF TENS.	MOMENTS ABOUT X, X₂ OF COMPR	MOMENTS ABOUT Y, Y₂ OF TENS.	MOMENTS ABOUT Y, Y₂ OF COMPR.
1	57 900		72000		1667000	
2		254000		318000		3780000
3a	32 900		182000		1 72000	
3b	3 100		42000		30000	
4		359 000		4667000		1 167000
5	45 300		992000		147000	
6a	50 600		1075000		1349000	
6b	423 000		8 989000		6 791 000	
6c	46 100		980 000		228000	
7	58200		1270 000		1 675000	
8		291 000		4 000000		8355000
9a	97 900		338000		27 88000	
9b	31,300		1 32000		900000	
Sum	871,400	904,000	14 093 000	8 985,000	15,768,000	13,342,000

UNITS = FORCES - POUNDS MOMENTS - INCH - POUNDS

Fig. 15 Summation of forces and moments

Location	*Longitudinal and Transverse Locked-in Stresses, psi. Drilling 1/4-in. hole* *Trepanned blocks*	*Soete method*	*Riparbelli method*
Near section No. 3 B1 Plate	−16,700 L*	−9,180 L	−10,980 L
	+4,000 T	+12,370 T	+10,600 T
Near section No. 3 B2 Plate	−18,600 L	+850 L	+12,300 L
	−2,900 T	+19,700 T	+29,600 T

* L = Longitudinal and T = Transverse.



		RELAXATION STRAIN AFTER FULL THICKNESS DRILLING MICROINCHES / INCH			DISTANCE FROM SR-4 STRAIN GAGE WIRE LOOPS TO TANGENT POINT OF HOLE MILLIMETERS		
	GAGE	R_1	R_2	R_3	d_1	d_2	d_3
STATION SB_1	OUT	+150	+10	-240	1.0	2.0	0.5
	IN	+150	-30	-100	1.7	2.3	0.6
	AVG.	+150	-10	-170	1.35	2.15	0.55
STATION SB_2	OUT	+120	-70	-280	0.7	3.0	0.4
	IN	+10	+150	-120	1.5	3.7	0.9
	AVG.	+65	+40	-200	1.1	3.35	0.65

Fig. 16 Data for quasi-destructive method

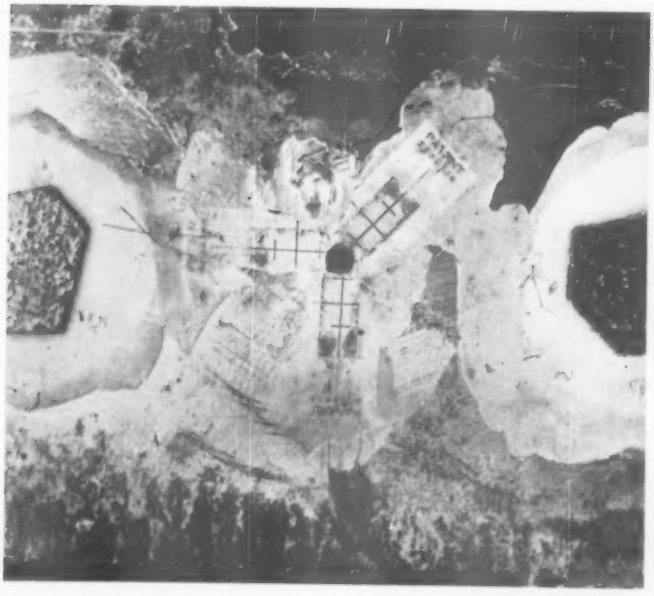


Fig. 17 View showing disposition of strain gages adjacent to 1/8-in. diameter hole

Drilling a small hole requires that the strain gages have maximum sensitivity. This makes it imperative to locate the gages as near as possible to the edges of the hole, a requirement which may easily interfere with the drilling operation. Both the Soete and Riparbelli methods require very accurate measurements of strains, and proper centering of the strain gage elements in order to maintain, in all orientations, uniform distances between the inner loops of the electric strain gages and the edges of the hole. Moreover, the drilled hole must be truly perpendicular to the plane of the plate. Undoubtedly, the locked-in stresses calculated by these theoretical methods are very sensitive to the above factors. When it is considered, for example, that strains of the order of ±20 micro inches correspond to a residual stress variation of the order of 5000 psi., it is readily seen that the quasi-destructive method needs considerable refinement in the experimental technique. This would suggest, perhaps, that consideration be given to drilling a hole larger than the 1/8-in. diameter used in this study.

CONCLUSION

The distribution pattern of the longitudinal and transverse locked-in stress for the girder tested is not uniform but varies from high tension to moderate compression. The longitudinal stress intensities are substantially represented by Fig. 14. Within the limits of the experimental errors, and inherent limitations in the methods of analysis used, the data satisfy the equilibrium requirements of internal forces and resisting moments.

ACKNOWLEDGMENT

This test was planned by the Structural Committee of the Welding Research Council. The box girder was constructed by the Ingalls Shipbuilding Corp. of Pascagoula, Miss. The work of installing the strain gages, subdividing, trepanning and reading the relaxed strains was carried out under the direct supervision of T. J. Dawson, metallurgist and member of that organization. The author is indebted to the members of the Committee for their many valuable suggestions, and particularly to Mr. Dawson for his cooperation in having made available considerable background data that have helped with the analysis.

References

1. Stang, A. H., and Jaffe, B. S., "Tests of Large Welded-Steel Box Girders," THE WELDING JOURNAL, **28** (3), Research Suppl., 89-s to 97-s (1949).
2. "The Design and Methods of Construction of Welded Steel Merchant Vessels," Board of Investigation Report, July 15, 1946.
3. Rosenthal, D., Hultgren, R., Martin, D. L., and O'Brien, M. P., "History of Residual Stresses in Welded Ships—The Use of X-Rays for the Determination of Stresses in Ship Plates," NDRC Research Project, Serial No. M-484, May 15, 1945.

4. De Garmo, E. P., Meriam, J. L., and Jonassen, Finn, "Residual Stresses in Ship Welding," NDRC Research Project, Serial No. M-370, Nov. 13, 1944.

5. Soete, W., "Measurement and Relaxation of Residual Stresses," THE WELDING JOURNAL **28** (8), Research Suppl., 354-s to 364-s (1949).

6. Riparbelli, Carlo, "A Method for the Determination of Initial Stresses," Princeton University Aeronautical Engineering Laboratory, Rept. 131, 1948.

Appendix A

Locked-In Stress—Study Box Girder No. 6

Strain gage station No.	*Measured data unit strain, in./in.* $\epsilon_3 \times 10^{-6}$	$\epsilon_{45} \times 10^{-6}$	$\epsilon_{90} \times 10^{-6}$	$\frac{\epsilon_3 - \epsilon_{90}}{2}$ $\times 10^{-6}$	$\frac{\epsilon_3 + \epsilon_{90}}{2} - \epsilon_{45}$ $\times 10^{-6}$	$\frac{\epsilon_3 + \epsilon_{90}}{2} + \mu\epsilon_{45}$ $\times 10^{-6}$	$\frac{\epsilon_3 + \epsilon_{90}}{2} + \mu\epsilon_{45}$ $\times 10^{-6}$	$\frac{E}{1-\mu^2}\left(\frac{\epsilon_3 + \epsilon_{90}}{2} + \mu\epsilon_{45}\right)$ σ_3, psi.	$\frac{E}{1-\mu^2}\left(\frac{\epsilon_{90} + \epsilon_3}{2} + \mu\epsilon_{45}\right)$ σ_{90}, psi.
1	−350	...	−860	−258.0	−105.0	−608	−965	−19,700	−31,300
2	−460	...	−520	−156.0	−138.0	−616	−658	−20,000	−21,300
3	+603	+312	−92	−27.6	+180.9	+375	+89	+18,600	+2,900
4	+420	+300	−285	−85.5	+126.0	+334	−159	+10,800	−5,200
5	−1176	−1016	−1427	−428.1	−352.8	−1604	−1780	−52,000	−57,700
6	+130	−344	−651	−195.3	+39.0	−65	−612	−2,100	−19,800
7	+430	−255	−752	−225.6	+129.0	+204	−623	+6,600	−20,200
8	+248	−200	−530	−159.0	+74.4	+80	−456	+2,880	−14,800
9	+355	−356	−710	−213.0	+106.5	+142	−604	+4,600	−19,600
10	+10	−90	−590	−177.0	+3.0	−167	−587	−5,400	−19,000
11	−580	−1210	−1074	−322.2	−174.0	−902	−1248	−29,200	−40,400
12	+470	−90	−325	−97.5	+141.0	+372	−184	+12,100	−6,000
13	+526	+210	−35	−10.5	+157.8	+516	+123	+16,700	+4,000
14	−360	−240	−260	−78.0	−108.0	−438	−368	−14,200	−11,900
15	−195	−100	−10	−3.0	−58.5	−198	−68	−6,400	−2,200
16	−620	−510	−340	−102.0	−186.0	−722	−526	−23,400	−17,000
17	−360	+200	+245	+73.5	−108.0	−286	+137	−9,300	+4,400
18	−280	+210	+265	+79.5	−84.0	−200	+181	−6,500	+5,900
19	−390	−120	+168	+50.4	−117.0	−340	+51	−11,000	+1,700
20	−395	−375	+75	+22.5	−118.5	−373	−43	−12,100	−1,400
21	−525	−430	+140	+42.0	−157.5	−483	−18	−15,600	−600
22	−660	−770	−660	−198.0	−198.0	−858	−858	−27,800	−27,800
23	−180	...	+200	+60	−54	−120	+146	−3,850	+4,700
24	−90	+130	−200	−60	−27	−150	−227	−4,850	−7,300
25	+580	+270	+75	+22	+164	+602	+239	+19,600	+7,700
26	+490	+90	−353	−106	+147	+384	−206	+12,400	−6,600
27	−1031	−1544	−1705	−510	−310	−1541	−2015	−49,500	−65,000
28	−180	−450	−640	−192	−54	−372	−694	−12,000	−22,500
29	+195	−290	−613	−184	+58	+11	−555	+350	−18,000
30	+75	−265	−575	−173	+22	−100	−553	−3,240	−18,000
31	+285	−161	−720	−216	+86	+69	−634	+2,250	−20,500
32	+120	−160	−590	−188	+36	−68	−554	−2,200	−18,000
33	−1106	−1104	−784	−235	−330	−1343	−1114	−43,200	−35,600
34	+602	+30	−405	−122	+181	+480	−224	+15,600	−7,200
35	+598	+190	−170	−52	+180	+546	+10	+17,700	+320
36	−200	−280	−400	−120	−60	−320	−460	−10,400	−14,800
37	−110	...	−80	−24	−33	−134	−113	−4,800	−3,650
38	−576	−320	−170	−52	−173	−628	−343	−20,300	−11,100
39	−620	−35	+145	+43	−186	−577	−41	−18,700	−1,330
40	−520	−30	+200	+60	−156	−460	+44	−15,000	+1,420
41	−455	−110	+125	+37	−136	−418	−11	−13,600	−350
42	−483	−2126	+160	+48	−145	−435	+15	−14,100	+480
43	−520	−440	+190	+57	−156	−463	+34	−15,000	+1,100
44	−550	−650	−580	−174	−164	−724	−744	−23,500	−24,000
45	−125	...	+125	+37	−37	−88	+88	−2,850	+2,850
46	−280	−301	−360	−108	−87	−398	−447	−12,900	−14,500
47	+587	+185	−185	−55	+173	+532	−12	+17,200	−390
48	+467	+115	−348	−104	+140	+363	−208	+11,700	−6,750
49	−1104	−1156	−1286	−386	−332	−1490	−1619	−48,300	−52,300
50	−60	−440	+2247	+675	−18	−615	+2229	−19,900	+72,500
51	+182	−180	−520	−156	+54	+26	−466	+840	−15,100
52	+142	−237	−513	−154	+42	−12	−471	−390	−15,300
53	+280	−271	−668	−200	+84	+80	−584	+2,600	−18,900
54	+300	−160	−600	−180	+90	+120	−510	+3,900	−16,500
55	−671	−1431	−1320	−396	−201	−1067	−1521	−34,600	−49,400
56	+720	+175	−150	−45	+216	+675	+66	+21,900	+2,140
57	+870	+340	+45	+13	+261	+883	+306	+28,600	+9,900
58	+80	−230	−140	−42	+24	+38	−116	+1,230	−3,770
59	−165	...	+80	+24	−50	−141	+30	−4,560	−970
60	−600	−460	−160	−48	−180	−648	−340	−21,000	−11,700
61	−695	−743	+1040	+312	−181	−293	−859	−9,700	−27,800
62	−400	+40	+300	+90	−138	−370	+162	−12,000	+5,250
63	−480	−155	+210	+63	−144	−417	+66	−13,500	+2,140
64	−600	−415	+165	+49	−180	−551	−15	−17,900	−500
65	−695	−498	+140	+42	−181	−563	−41	−18,200	−1,330
66	−486	−630	−606	−182	−149	−678	−457	−22,000	−14,900
67	−115	...	+230	+69	−34	−46	+196	−1,500	+6,400
68	−210	−384	−170	−51	−63	−261	−233	−8,500	−7,500
69	+625	+225	+25	+75	+198	+700	+213	+22,700	+6,900
70	+310	+295	−185	−56	+93	−254	−92	+8,200	−3,000
71	−1531	−991	−1471	−441	−459	−1972	−1930	−63,900	−62,500
72	+420	−230	−680	−198	+126	+222	−534	+7,200	−17,300
73	+635	−165	−715	−214	+190	+421	−525	+13,600	−17,000
74	+680	−20	−535	−160	+204	+520	−331	+16,800	−10,700
75	+760	+225	−702	−229	+228	+531	−534	+17,200	−17,300
76	+270	−40	−450	−135	+81	+135	−369	+4,400	−12,000
77	−970	−1204	−980	−294	−291	−1264	−1271	−41,000	−41,200
78	+465	−60	−297	−89	+140	+376	−157	+12,200	−5,100
79	+725	+330	−140	−42	+218	+683	+78	+22,100	+2,500
80	−90	−100	−120	−36	−27	−126	−147	−4,100	−4,800
81	−265	...	+90	+27	−80	−238	+10	−7,700	+300
82	−696	−576	−330	−99	−209	−795	−539	−25,800	−17,500
83	−600	+35	+205	+62	−207	−628	−2	−20,300	−100
84	−547	−70	+125	+38	−164	−589	−39	−16,500	−1,300
85	...	−145	+165	+50	...	...	...	...	...
86	−315	−230	+195	+58	−94	−257	+101	−8,300	+3,300
87	−390	−300	+205	+62	−117	−328	+88	−10,600	+2,900
88	−641	−610	−546	−164	−192	−805	−738	−26,100	−23,900

NOTE: Locked-in stresses have opposite signs to those tabulated above.
ϵ = Strain; σ = stress; τ = shear stress; E = 29.5 x 10^6 psi.; μ = 0.30; $E/(1 - \mu^2)$ = 32.4 x 10^6 psi; $G = E/2(1 + \mu)$ = 11.3 x 10^6 psi.

Appendix B

CALCULATION OF LOCKED-IN STRESSES

1. Trepanned Plug

$$\sigma_1 = \frac{E}{1-\mu^2}[\epsilon_1 + \mu\epsilon_2]$$

where

ϵ_1 = relaxed strain in longitudinal direction
ϵ_2 = relaxed strain in transverse direction
E = modulus of elasticity
μ = Poisson's ratio
σ_1 = longitudinal residual stress

2. Soete Method (Reference 5)

$$\sigma_{-\infty} = \frac{E}{1-\mu^2}[\epsilon_{-\infty} + \mu\epsilon_{+\infty}]$$

where

$\epsilon_{-\infty} = K_1\epsilon_{-\infty}' + K_2(\epsilon_0' + \epsilon_{+\infty}' + \epsilon_{-\infty}')$
$\epsilon_{+\infty} = K_1\epsilon_{+\infty}' + K_2(\epsilon_0' + \epsilon_{+\infty}' + \epsilon_{-\infty}')$
ϵ_0' = relaxed strain on 45° axis
$\epsilon_{+\infty}'$ = relaxed strain in transverse direction
$\epsilon_{-\infty}'$ = relaxed strain in longitudinal direction
$K_1 = \frac{B}{B'}, B = \frac{1+\mu}{2}, B' = -\frac{2a^2}{r_1r_2}\left[1 - \frac{(1+\mu)}{4}a^2\frac{(r_1^2 + r_1r_2 + r_2^2)}{r_1^2r_2^2}\right]$
a = radius of hole
r_1 = distance from center of hole to near edge of gage
r_2 = distance from center of hole to far edge of gage
$(r_2 - r_1)$ = gage length
$K_2 = \frac{1}{3}\left[\frac{A}{A'} - \frac{B}{B'}\right], A = \frac{1-\mu}{2}, A' = -\left[\frac{1+\mu}{2}\right]\frac{a^2}{r_1r_2}$
$\sigma_{-\infty}$ = longitudinal residual stress

3. Riparbelli Method (Reference 6)

$$\sigma_1 = \frac{E}{(1-\mu^2)(K_1^2 - K_2^2)}[\phi_1(K_1 - \mu K_2) - \phi_2(K_2 - \mu K_1)]$$

K_1 and K_2 are functions of r/a lifted from Tables 10 and 11 of reference 2.

r = distance from center of hole to center of gage
a = radius of drilled hole
ϕ_1 = relaxed strain in longitudinal direction
ϕ_2 = relaxed strain in transverse direction
σ_1 = residual stress in longitudinal direction

NOTE: ϵ_1, ϵ_2, $\epsilon_{-\infty}$, $\epsilon_{+\infty}$ and ϕ_1, ϕ_2 are orthogonal strains.

Impact Tests of Welded Austenitic Stainless Steels

by V. N. Krivobok and R. D. Thomas, Jr.

THE impact data presented here were obtained through the combined efforts of the research laboratories of The International Nickel Co. and the Arcos Corp. The plates for welding were furnished by several of the steel producers. The welding and analyses of the weld metals were done by the Arcos Corp. The heat treating, machining and testing were done by The International Nickel Co.

Weld metals whose composition conformed to the following A.I.S.I. types were tested: types 301, 302,

Table 1A—Analysis of Steel

Test No.	Type of Plate	C	Mn	P	S	Si	Ni	Cr	Mo	Cb	Ti
1	301	.09	1.04	.032	.007	.53	7.91	17.68			
2	302	.06	.46	.015	.022	.47	9.26	18.92			
3	304	.056	.40	.014	.010	.41	9.50	18.10			
4	304	"	"	"	"	"	"	"			
5	310	.07	1.73	.018	.007	.46	21.02	26.76			
6a	316	.062	1.89	.027	.017	.54	12.25	17.55	2.13		
6b	316	.062	1.90	.029	.016	.54	12.39	17.23	2.25		
7	316	"	"	"	"	"	"	"	"		
8	317	.062	2.14	.023	.016	.58	12.67	18.58	3.28		
9	317	"	"	"	"	"	"	"	"		
10	318	.057	1.91	.024	.016	.63	13.63	18.34	2.14	.73	
11	318	.066	2.01	.023	.017	.75	13.09	17.75	2.34	.86	
12	321	.05	1.20	.026	.010	.54	9.42	17.69			.51
13	347	.048	1.59	.018	.014	.58	10.58	18.49		.78	
14	347	"	"	"	"	"	"	"		"	
15	347	"	"	"	"	"	"	"		"	

V. N. Krivobok is in charge of Stainless Steel Section, Development and Research Div., The International Nickel Co., Inc., New York, N. Y., and **R. D. Thomas, Jr.,** is Vice-Pres., in Charge of Research and Engineering, Arcos Corp., Philadelphia, Pa.

Table 1B—Analysis of Weld Metal

Test No.	Type of Electrode	C	Mn	P	S	Si	Ni	Cr	Mo	Cb
1	301	.146	.76	.010	.013	.59	6.80	16.67		
2	302	.159	1.65	.017	.022	.49	8.56	18.18		
3	304	.060	1.68	.019	.016	.48	8.67	18.19		
4	308	.054	1.73	.017	.015	.51	10.80	20.22		
5	310	.104	1.80	.020	.018	.54	21.66	25.72		
6a	316	.060	1.95	.019	.007	.49	13.31	16.88	2.19	
6b	316	"	"	"	"	"	"	"	"	
7	316	.052	1.80	.016	.006	.50	12.25	20.56	2.20	
8	317	.057	1.35	.022	.009	.48	13.28	18.03	3.24	
9	317	.060	1.68	.014	.003	.28	14.11	20.31	3.76	
10	318	.050	1.71	.028	.006	.53	12.65	17.01	2.19	.70
11	318	.064	2.05	.027	.003	.62	12.73	18.37	2.06	.77
12	347	.070	1.72	.020	.010	.53	10.23	19.58		.61
13	347	.063	1.53	.020	.014	.50	11.61	19.11		.68
14	347	.070	1.72	.020	.010	.53	10.23	19.58		.81
15	347 (a)	.056	1.66	.022	.006	.76	10.04	19.65		.94

(a) Titania type coating. All other electrodes had lime type coating.

[a] Obtained from all weld metal pads, prepared and analyzed in accordance with A.S.T.M. Tentative Standard A296-48T.

Table 2—Impact Data on Plate Material

Test No.	Type of Plate	Ft. Lbs. At Room Temperature		-105° F.		-320° F.		
1	301	67	94.5	90.5	96	80	78.5	
2	302	76	74	76	78.5	70.5	69	
3	304	74	66	70	66	70	66	
4	304	70	69.5	70	66	67	66	
5	310	78.5	81	78	68.5	61	61	
6a	316	73.5	78	66	61	64.5	71.5	63
6b	316	86.5	83.5	76.5	80.5	80.5	75	
7	316	79.5	80	72.5	70	68	68.5	
8	317	88	75	95	84.5	57.5	56	
9	317	same as No. 8						
10	318	82 72	70 61	53	56.5	41	42	
11	318	82.5	80	58	68.5	52		
12	321	70	69	71	70.5	48	47	
13	347	59	68	53.5	56.5	54	56.5	
14	347	58	60	51.5	53.5	55	50.5	
15	347	56.5	58	51.5	59	52.5	63.5	

Table 3—Impact Data on Weld Metal

Test No.	Type of plate	Type of electrode	Heat treatment*	Per cent ferrite‡	Room temperature			−105°F.			−320°F.		
1	301	301	as welded		35	35	36	20	22		4.5	5.5	
					37.5	38.5							
			annealed		42	41		31	30		24	24	
2	302	302	as welded		33	32	34	25.5	26.5		9	10	
					32.5			28					
					40	37		34.5	30.5		24.5	27.5	
3	304	304	as welded		36	34	32	27.5	24		22.5	18	
					33	36.5							
			annealed		49	41	42.5	41.5	39		32	32.5	42
4	304	308	as welded		31	32	32	21	25	22.5	19.5	18	
					32.5						13.5		
			annealed		35.5	37.5		30	29.5		30.5	30	
5	310	310	as welded		36.5	35.5		31.5	31.5	26	23.5	24	
					38	35							
			annealed		34	29.5		28.5	27.5		20	18	
6a	316	316	as welded	0.5%	34.5	27.5		27.5	25		19	14	21
					30.5	27							
6b			stress relieved		34	31.5	30	26.5	24.5		14	13	
			stabilized		26	29	30	20.5	21.5		14.5	11	
6a			annealed		31.5	36		29.5	28		22	22	
7	316	316	as welded	8.0%	32	31		29	27.5		17.5	19.5	
			stress relieved		27	25		17.5	16.5		7.5	7	
			stabilized		11.5	10.5		7.5	7		3	2.5	
			annealed		31.5	40.5	36.5	28	37	33	23.5	27.5	
					40								
8	317	317	as welded	2.0%	22.5	20.5		16	17		8.5	10	13.5
			annealed		21	20.5		17	15.5		10.5	15.5	17
9	317	317	as welded	5.5%	12	11	10	7	8		4	4	
						9.5	14.5						
			annealed		11.5	10		6.5	5		3	2.5	
10	318	318	as welded	none	27.5	27.5		22.5	22.5		9	17	17.5
			stress relieved		30	22.5		25.5	22.5		17.5	8.5	18
			stabilized		22	21		15	16		13	12.5	
			annealed		33	30	29.5	29.5	27.5	20.5	21.5	19	
11	318	318	as welded	0.5%	20.5	23	15	15	18		11.5	10.5	
					22	20							
			stress relieved		21.5	19	17	14	15.5		7	9	10
			stabilized	none	9.5	8		8.5	6.5	5.5	5.5	5	
			annealed		26	25		18.5	22.5		16	10	18
12	321	321	as welded	§	32	32		27	24	26.5	25.5	18	18
											22		
			annealed		32	29		32	36	28	23	26.5	23
										28.5			
13	347	347	as welded	none	25.5	29		22.5	18.5		20	20	18
								22	27				
			stress relieved		27	25		20	20			13	14
			stabilized		22	22		17	14		15.5	13.5	
			annealed		26	24		25.5	25	24.5	17	16	
											20	20	
14	347	347	as welded	3.5%	27	33		28.5	26.5	20.5	22	16	19
											17		
			stress relieved		26.5	24		15.5	14.5		13	9.5	9
			stabilized		22	19		18	15		7	20	14
											14.5		
			annealed		27	24.5		27.5	24.5	20	26	23.5	22.5
									29.5				
15	347	347(a)	as welded		28	25		22.5	23	17.5	26.5	17.5	13
											16		
			annealed		31	28		27	20	21.5	22.5		21

* Heat treatments were as follows:
as welded
stress relieved 1200° F. 2 hrs.
stabilized 1550° F. 2 hrs.
annealed 1950° F. ½ hr. water quenched.

‡ Ferrite was determined by use of a Aminco-Brenner Magne-Cage, as outlined in "Detection of Ferrite by its Magnetism," by T. V. Simpkinson & M. J. Lagne, "Metal Progress," Feb. 1949, page 164.

§ Not measured but probably the same as test No. 14 since the same electrode was used.

(a) Titania type coating. All other electrodes had lime type coating.

304, 308, 310, 316, 317, 318 and 347, (the last with lime and titania coated electrodes). In the case of types 316, 317, 318 and 347, two different analyses of weld metals were tested. The composition of the electrode was so balanced that the two analyses of each would yield weld metal with different percentage of ferritic phase. Tests were carried out at room temperature, −105 and −320° F. All welds were tested in the as-welded and the annealed (1950° F., 1/2 hr. and water quenched) conditions. In addition the types 316, 318 and 347 were tested after stress relieving at 1200° F. for 2 hr. and after stabilizing at 1550° F. for 2 hr. Impact tests were also made on the plate materials in the as-received (quenched annealed) condition.

Plates approximately 4 x 13 x 1/2 in. thick were obtained from various producers, and after machining two plates of the same analysis were welded together along the 13-in. sides. The weld joint contained an included angle of 60° with a root face of 1/16 in. and an opening of 3/32 in. The electrodes used were 5/32 in. in diameter and the weld was completed in five passes at 22–25 v. d. c. with 120–130 amp., reverse polarity. The plates were not preheated prior to welding and the interpass temperature was limited to 150–200° F.

Table 1A gives the heat analyses of the plate materials which were reported by the supplier. Table 1B gives the analyses of the weld metals as determined from standard weld-metal pads.

After discarding about 3/4 in. from each end of the 13-in. weld bead the remainder was cut into blanks suitable for the machining of the Charpy keyhole impact specimens, subsequent to any necessary heat treatment. After heat treating the blanks were machined into Charpy keyhole impact specimens. Approximately the same amount of metal was removed from the top of the weld as from the under side of the weld. The specimens were notched through the root of the original weld.

The specimens were then tested at room temperature, −105 and −320° F. A mixture of dry ice and alcohol was used to cool the specimens to −105° F. and a bath of liquid nitrogen to cool the specimens to −320° F. All impact specimens were held at the test levels for a minimum of 30 min. prior to testing.

Table 2 gives the impact data obtained on the plate materials in the as-received (quench annealed) condition. Table 3 gives the data obtained on the weld metal.

Standardization of Welding in Germany*

The new Welding Standards Committee in Germany has eleven technical committees, each with an Eastern Division and a Western Division. The Chairman of the main committee is Dr. R. Kühnel, Director of the German Railways. The Eastern and Western Divisions have their own committees which, however, work closely together.

Committee 1—Welding Equipment: (*a*) Apparatus for Gas Generation and Preparation and (*b*) Gas Cylinders.

Committee 2—Welding Terms and Symbols.

Committee 3—Gas Cutting and Scarfing.

Committee 4—Joints for Welding.

Committee 5—Filler Metal for Welding Iron and Steel.

Committee 6—Apparatus for Electric Welding.

Committee 7—Filler Metal and Fluxes for Nonferrous Welding.

Committee 8—Health and Safety: (*a*) Medical Section and (*b*) Accident Section.

Committee 9—Welding Codes: (*a*) Structural Steel; (*b*) Machinery; (*c*) Shipbuilding; (*d*) Rolling Stock; (*e*) Boilers and Pressure Vessels and (*f*) Tanks and Piping.

Committee 10—Methods of Testing.

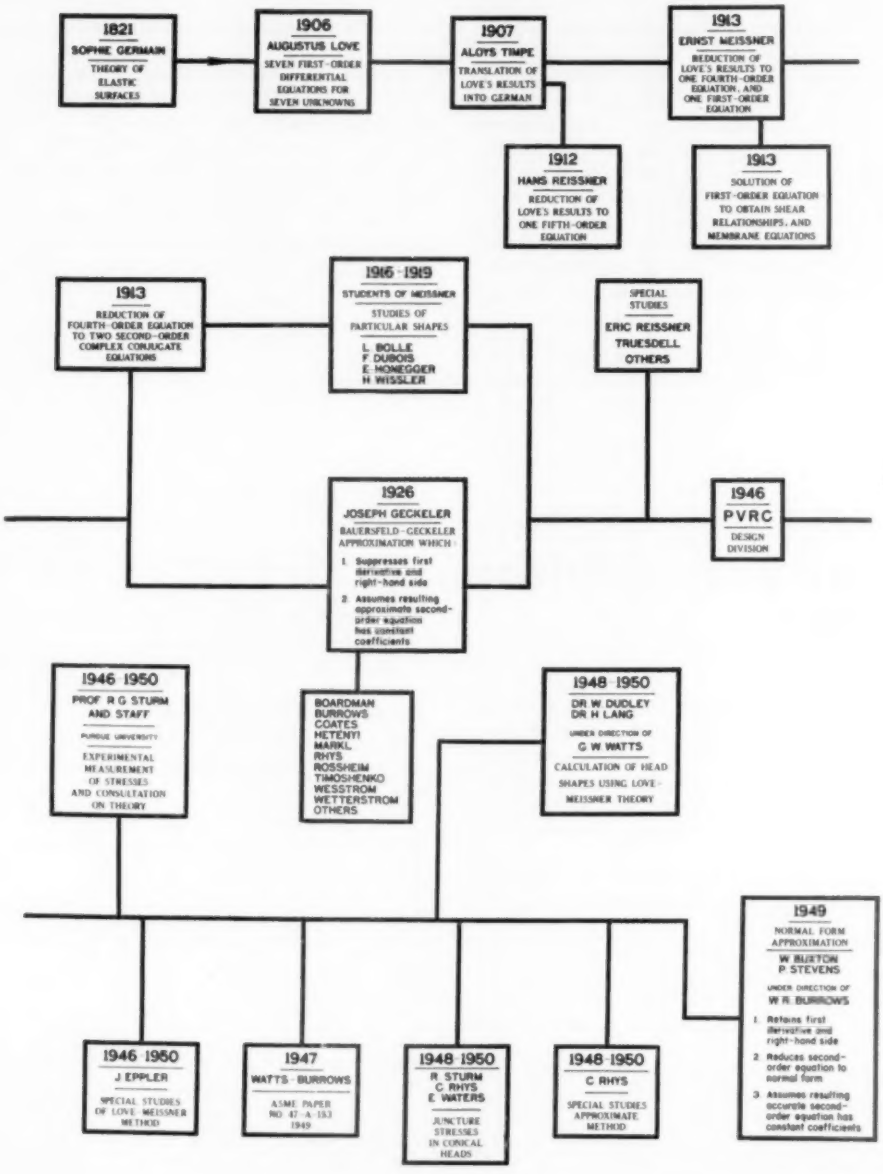
Committee 11—Weldability of Base Metal: (*a*) Iron and Steel; (1) sheets and (2) plates and (*b*) Nonferrous.

The specifications for gas welding and cutting torches, regulators, hoses and allied equipment are being revised completely, as are the standards on terms and symbols. The Standard DIN 2559 on "Types of Joints" is being made more comprehensive to include all types of welded joints in boilers, apparatus and piping. The Standard DIN 1913 on welding rods for arc and gas welding of steel is being revised. Rods will be classified according to type of coating and special welding characteristics. All essential properties of each class of electrode will be listed. The Committee on Welding Codes is assembling information on all welding codes in existence in Germany with a view toward standardizing testing conditions.

* Published in Schweissen und Schneiden, pp. 108–109, May 1950. (Abstracted by Dr. G. E. Claussen)

Elastic Theory of Pressure Vessel Heads

Brief history, prepared by the Design Division, of work on elastic theory of pressure vessel heads under pressure—showing work prior to PVRC and work either actuated by or integrated with PVRC (except for independent studies by Eric Reissner and others)



JACKSON
GROUND CLAMP
No. 2/0

GROUNDWORK

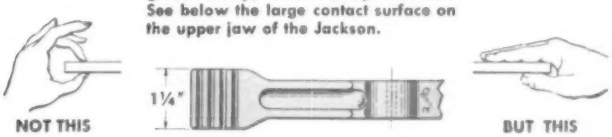
for Profitable Welding

Arc Welders must put on the heat. But only at one point: at the end of the electrode. And any heat elsewhere along the welding circuit means current wasted.

Don't rely on makeshift ground connections, inefficient and unwieldy C-clamps and plates, and on hastily made cable splices, ineffective and unstable.

Wherever connections must be made in the circuit, choose Jackson cable fittings which provide ample metal-to-metal contact to ease the flow, and stop the loss of current.

For greater metal-to-metal contact in a ground clamp, which would you choose? See below the large contact surface on the upper jaw of the Jackson.



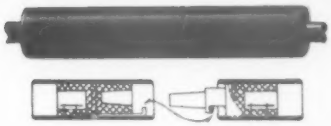
JACKSON GROUND CLAMPS

When choosing between ground clamps, take a close look at the Jackson, and note the large, flat contact surface of the copper alloy upper tong. It provides the greatest and surest conductivity between the clamp and the work.

Other features: Simple, rugged design: the upper tong for contact, the lower for pinch. Greater leverage at the "handle" end of the tongs; they go easier *on*, easier *off*.

Recent improvements: New music wire coil spring . . . complete spring insulation at both ends against accidental arcing, and to prolong spring life . . . new, larger pivot bolt for greater strength, where it counts most.

Double Economy: The Jackson Ground Clamp, eliminating loss of valuable welding current, will pay for itself in very little time. And because its price is low, you may be sure of *double economy* when you buy Jackson's.



JACKSON "QUIK-TRIK" CABLE CONNECTORS

The safest way of making cable extensions. By connecting the female unit to the cable lead, the live cable end is always well insulated when not in use. Units lock tight by a twist of the hand. To avoid delays in your shop, keep your stock of replacement holders on hand with a length of cable and a male unit of the cable connector fastened to them. Then, if a holder needs replacing, get a spare and connect it in a minute.

JACKSON CABLE SPLICERS

Cable ends make adequate metal-to-metal contact with the copper alloy splicer, clamped, soldered, or brazed. For permanent, well insulated extensions; time saving, economical.

JACKSON CABLE LUGS

Sturdy high copper content alloy lugs for both mechanical and soldered cable connection. They are available in three sizes, each in a 180° and a 45° design.

Please specify type required

180°

45°

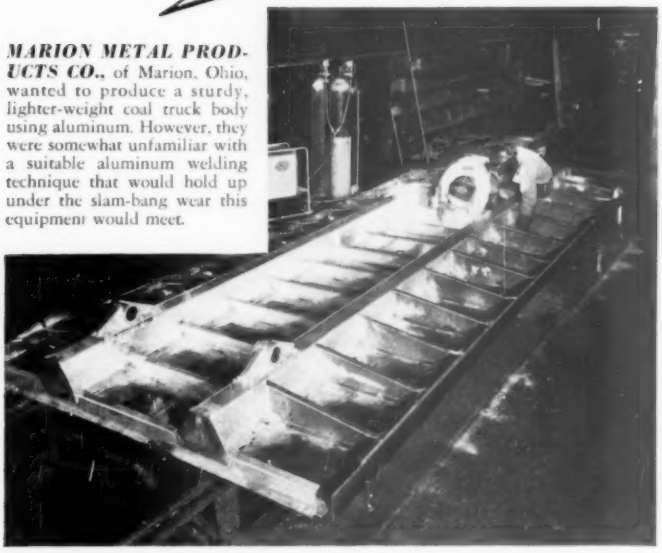
See your Jackson Distributor for prompt delivery
Also ask him about Jackson Electrode Holders, Eyeshields, and Safety Goggles

JACKSON
PRODUCTS
WARREN · MICHIGAN

MODEL	CABLE SIZE	CABLE CONNECTION	CAPACITY	GROUND CLAMP		CONNECTOR	SPLICER	LUG
				jaw opening	price	price	price	price
No. 1	4 thru 1/0	mechanical or soldered	300 amp	1⅛"	2.75	2.95	1.60	.80
No. 2/0	1/0 and 2/0	mechanical or soldered	500 amp	1¼"	3.50	3.75	1.85	.90
No. 4/0	3/0 and 4/0	soldered only	500 amp	1¼"	3.25	3.50	1.50	.80

New Aircomatic® Welding process permits building lighter coal truck . . . with more payload

MARION METAL PRODUCTS CO., of Marion, Ohio, wanted to produce a sturdy, lighter-weight coal truck body using aluminum. However, they were somewhat unfamiliar with a suitable aluminum welding technique that would hold up under the slam-bang wear this equipment would meet.



Charles Bruno, Reynolds Metal Company's welding specialist, and Dana V. Wilcox, Airco technical sales service specialist were consulted and recommended to the customer the use of the new Aircomatic Process—an inert, gas-shielded arc welding method. Fabricated with the Aircomatic Process, the truck was found to be very rigid, even under full load . . . and the total weight of the aluminum body was 2345 lbs. as against the former body weight of 4800 lbs. This tremendous decrease in body weight permitted the loading of one more ton of coal . . . a payload increase of 10%.

If you are interested in a fast and more economical effort of fabricating your products from aluminum, aluminum or silicon bronze, stainless and nickel clad steels, it will pay you to investigate the advantages of Aircomatic welding. For technical service or a copy of the Aircomatic welding bulletin ADC-661A, please write to your nearest Airco office.

AIRCO **AIR REDUCTION**

Offices in Principal Cities

TECHNICAL SALES SERVICE—ANOTHER AIRCO PLUS-VALUE FOR CUSTOMERS

news about AIRCO products

AIRCO HORNET 36A D-C WELDER

The "Hornet 36A" Arc Welder is a heavy-duty, light-weight machine designed to furnish smooth, steady current for every DC arc welding job.

The "36A" features simplified control of current output by means of a sturdy hand-wheel mounted on the control cabinet. Close calibration of the current dial eliminates the need for meters. Easy reversal of the polarity of the welding terminals is provided by a sturdy polarity switch. 200, 300 and 400 ampere sizes are available.

AIRCO HELIWELDING EQUIPMENT

All high capacity Heliweld holders are water-cooled to provide sufficient cooling for high currents used. There's the Air-Cooled Manual Holder for light, general-purpose work . . . the Water-Cooled Manual Holder for heavier, general-purpose work . . . the Machine Holder for semi-automatic installations . . . the Automatic Head for the fully automatic operations. Also available is a Heliweld "Bumblebee" for AC heliwelding. This machine has all controls for current, gas and water within its housing, PLUS a one unit power supply.

For more information, write your nearest Airco office today for a free copy of Heliwelding Catalog No. 9.

* * *

Air Reduction supplies Oxygen, Acetylene and other industrial gases . . . Calcium Carbide . . . and a complete line of gas cutting machines, gas welding apparatus and supplies, plus arc welders, electrodes and accessories. Ask us about anything pertaining to gas welding and cutting, and arc welding . . . we'll be glad to help you.